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Volume 2 of 5

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U.S. Department of Energy
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Report Coordinated By
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4.0 WASTE TREATMENT TECHNOLOGY

4.0 WASTE TREATMENT TECHNOLOGY

This section describes conceptual processes and facilities for treating gaseous and various transuranium (TRU) wastes produced during the postfission portion of the ^{Light Water Reactor} (LWR) fuel cycle. The goal of the treatment process for TRU wastes and for long-lived radionuclides removed from the gaseous waste streams is to convert these wastes to stable products suitable for placement in geologic isolation repositories. The treatment concepts are based on available technology. They do not necessarily represent an optimum design but are representative of what could be achieved with current technology. In actual applications it is reasonable to expect that there could be some improvement over these concepts that might be reflected in either lower costs or lower environmental impacts or both. These conceptual descriptions do provide a reasonable basis for cost analysis and for development of estimates of environmental impacts.

The waste treatment technologies considered here include:

- Section 4.1 High Level Waste Solidification
- Section 4.2 Packaging of Fuel Residue
- Section 4.3 Failed Equipment and Noncombustible Waste Treatment
- Section 4.4 General Trash and Combustible Waste Treatment
- Section 4.5 Degraded Solvent Treatment
- Section 4.6 Dilute Aqueous Waste Pretreatment
- Section 4.7 Immobilization of Wet and Solid Wastes
- Section 4.8 Off-gas Particle Removal Systems
- Section 4.9 Fuel Reprocessing Plant Dissolver Off-gas Treatment
- Section 4.10 Process Off-gas Treatment
- Section 4.11 Fuel Reprocessing Plant Atmospheric Protection System

Treatment alternatives considered in this document have been selected primarily on the basis of available technology as identified in the ERDA report, Alternatives for Managing Wastes from Reactors and Post-fission Operations in the LWR Fuel Cycle. Where possible at least two available technology alternative concepts are described for treatment of each waste type. However, in two cases, failed equipment and noncombustible waste treatment (Section 4.3) and degraded solvent treatment (Section 4.5), only one concept is described since there are no significant alternative concepts available. In two cases, Packaging of Fuel Residues (Section 4.2) and the Atmospheric Protection System (Section 4.11), three alternatives are described.

In two sections, Section 4.6 and 4.8, the descriptions are limited to generic discussions of facilities; no specific facilities are described. The processes presented in Section 4.6 for dilute aqueous waste pretreatment are often more closely related to the main recycle process flowsheet than to treated waste requirements. The concentrated waste streams produced by these processes are subject to further treatment described in other sections. Section 4.8 discusses off-gas particle removal through the application of high-efficiency air filtration systems. Such systems are used throughout a reprocessing or mixed oxide fuel fabrication plant and description of specific individual facilities is inappropriate here. Treatment

and packaging of the filters used in particle removal systems are described in Section 4.4. The facilities generically described in Sections 4.6 and 4.8 were identified in the ERDA report⁽¹⁾ as waste treatment facilities; their functions are discussed here to complete the discussion of waste treatment alternatives.

REFERENCE FOR SECTION 4.0

1. Alternatives for Managing Wastes from Reactors and Post-fission Operations in the LWR Fuel Cycle. ERDA-76-43, Energy Research and Development Administration, Washington, DC, May 1976.

4.1 HIGH LEVEL WASTE SOLIDIFICATION

4.1 HIGH-LEVEL LIQUID WASTE SOLIDIFICATION

High-level liquid waste (HLLW) is defined by the Code of Federal Regulations as the aqueous waste resulting from operation of the first cycle solvent extraction system and the concentrated wastes from subsequent extraction cycles (or their equivalent) in a facility for reprocessing irradiated reactor fuels.⁽¹⁾ HLLW contains over 99% of the fission products and transplutonium elements extracted from spent fuel at an FRP and thus incorporates most of the radioactivity associated with reprocessing LWR fuel. Regulations stipulate that HLLW must be solidified within 5 years after reprocessing. The solidified waste must be placed in sealed containers prior to shipment offsite. The sealed containers, commonly called canisters, must be transferred to a Federal repository no later than 10 years after reprocessing.

Table 4.1.1 shows the composition of the reference HLLW. The inert portion of this waste (i.e., chemicals added during reprocessing) can vary significantly in composition.⁽²⁾ Except for gadolinium, which is assumed to have been added as a soluble neutron absorber for criticality safety during the dissolving step, the reference HLLW is "clean"; some HLLW compositions are "dirtier" because they contain much higher concentrations of sodium and iron. The main effect of chemical additions to the waste is to increase the volume of the final solidified product and thus dilute its activity and heat density.

The nitric acid concentration of the reference HLLW is 2.0 M. To obtain such a low HNO_3 concentration in HLLW without a storage holdup for radiolytic decomposition of the acid would probably require a denitration step. Such denitration can easily be done using established technology during HLLW concentration in the main plant.⁽³⁾ The technology for denitrating HLLW to much lower HNO_3 concentrations as part of the solidification process is being developed, particularly in Europe.⁽⁴⁾ Denitration during processing would result in a decrease in ruthenium volatility during solidification, thus further decreasing the radioactive release from HLLW solidification facilities to levels below those estimated for the reference facility in this report.

Prior to shipment to a Federal repository, the high-level waste must be stored for several years in either a liquid or solid form after its initial production in the fuel reprocessing plant. This storage allows for radioactivity decay to reduce its heat generation rate. This cooling is required to permit use of larger and more economically sized canisters and to insure that the temperature of the solidified high-level waste (SHLW) during shipment or when placed in a repository remains below specifications for waste and/or repository stability. The required cooling period for the waste depends on the age of the fuel at the time of reprocessing and the size and design of the solidified waste canister. The heat generation rate in the reference HLLW is shown as a function of time in Table 4.1.2.

Solidification of HLLW has not been demonstrated in an operating commercial reprocessing plant. A large amount of research and development, however, has been done in the U.S. and abroad to develop technology for converting HLLW into granular powder, called calcine, or into glass.^(5,6,7) The results of this work, as well as experience at Department of Energy (DOE) facilities, can serve as a realistic basis for conceptual design of processes for HLLW solidification in an industrial reprocessing plant.

4.1.2

TABLE 4.1.1. Reference HLLW Composition

Before Treatment ^(a)		As Oxide ^(b)	
Constituent	Concentration, moles/l @ 567 l/MTHM	Constituent	Oxides, kg/MTHM
Inerts (Reprocessing chemicals):		Inerts (Reprocessing chemicals):	
Na	0.007	Na ₂ O	0.12
Fe	0.036	Fe ₂ O ₃	1.6
Cr	0.0064	Cr ₂ O ₃	0.28
Ni	0.0023	NiO	0.10
P	0.028	P ₂ O ₅	1.1
Gd	0.10	Gd ₂ O ₃	10.0
		Subtotal	13.2
Fission Products:		Fission Products:	
Rb	0.0056	Rb ₂ O	0.30
Sr	0.014	SrO	0.84
Y	0.0074	Y ₂ O ₃	0.48
Zr	0.058	ZrO ₂	4.2
Mo	0.055	MoO ₃	4.6
Tc	0.013	Tc ₂ O ₇	1.2
Ru	0.036	RuO ₂	2.7
Rh	0.0065	Rh ₂ O ₃	0.47
Pd	0.0023	PdO	1.6
Ag	0.0010	Ag ₂ O	0.069
Cd	0.0014	CdO	0.102
Sn	0.0007	SnO ₂	0.061
Sb	0.0002	Sb ₂ O ₃	0.015
Te	0.0071	TeO ₂	0.65
Cs	0.031	Cs ₂ O	2.6
Ba	0.018	BaO	1.5
La	0.014	La ₂ O ₃	1.3
Ce	0.028	CeO ₂	2.7
Pr	0.012	Pr ₆ O ₁₁	1.3
Nd	0.043	Nd ₂ O ₃	4.1
Pm	0.0009	Pm ₂ O ₃	0.087
Sm	0.0090	Sm ₂ O ₃	0.89
Eu	0.0019	Eu ₂ O ₃	0.19
Gd	0.0012	Gd ₂ O ₃	0.12
		Subtotal	32.1
Actinides:		Actinides:	
U	0.035	U ₃ O ₈	5.7
Np	0.004	NpO ₂	0.64
Pu	0.0005	PuO ₂	0.07
Am	0.003	Am ₂ O ₃	0.50
Cm	0.0007	Cm ₂ O ₃	0.11
		Subtotal	7.0
		Total	52.3

a. As nitrate salts in approximately 2 M HNO₃.

b. The waste constituents are converted to their oxide form in the treatment process.

4.1.3

TABLE 4.1.2. HLLW Heat Generation Rate for Reference Cases

Time after Reprocessing, yr	Heat in Waste ^(a) from 1 MTHM, W								
	U and Pu Recycle			U Recycle, Pu in Waste			U Recycle, Pu Separated		
	Fission Products	Actinides	Total	Fission Products	Actinides	Total	Fission Products	Actinides	Total
0	6,450	640	7,090	6,310	315	6,625	6,310	184	6,494
1	3,760	347	4,107	3,700	218	3,918	3,700	82.3	3,782
2	2,470	278	2,748	2,440	199	2,639	2,440	59.5	2,499
3	1,790	257	2,047	1,790	197	1,987	1,790	53.5	1,843
4	1,420	246	1,666	1,430	198	1,628	1,430	51.2	1,481
5	1,210	237	1,447	1,220	200	1,420	1,220	49.6	1,270
6	1,079	229	1,299	1,090	202	1,292	1,090	48.2	1,138
7	975	222	1,197	996	204	1,200	996	46.9	1,043
8	908	214	1,122	930	206	1,136	930	45.7	976
9	857	207	1,064	880	207	1,087	880	44.5	925
10	817	201	1,018	839	209	1,048	839	43.4	882
50	290	65.6	355.6	299	215	514	299	19.9	319
100	87.6	31.8	119.4	90.3	188	278.3	90.3	13.4	104
500	0.06	14.1	14.16	0.06	86.4	86.5	0.06	6.6	6.66
1,000	0.02	7.5	7.52	0.02	49.7	49.7	0.02	3.31	3.33
10,000	0.02	1.33	1.35	0.02	12.3	12.3	0.02	0.395	0.415
100,000	0.013	0.103	0.121	0.01	0.867	0.877	0.01	0.073	0.083
1,000,000	0.001	0.113	0.114	0.001	0.291	0.292	0.001	0.110	0.111

a. Out of reactor 1.5 years; 0.5% of uranium and plutonium remain in waste after reprocessing.

A fluidized bed calciner was licensed for construction to convert HLLW to calcine in General Electric Company's Midwest Fuel Recycle Plant. The calciner was installed in the plant, but no application for an operating license was made because of General Electric Company's decision not to activate the reprocessing plant. Three companies associated with or who have considered LWR fuel reprocessing facilities, Nuclear Fuel Services, Allied General Nuclear Services, and Exxon Nuclear Co., have proposed HLLW management plans that include vitrification as either their mainline process or principal option, as have the major European countries. In line with these plans, the reference HLLW solidification process for this report is vitrification. Conversion of HLLW to a calcine product is described as an alternative.

Several other alternative solidified HLW products have been, or are being, investigated. These were identified in ERDA-76-43⁽²⁾ and include sintered glass, super calcine, metal matrices, glass ceramics, coated pellets and inorganic ion-exchange media. None of these solidified wastes forms are as well developed as waste glass or calcine, but it is possible that they may provide improved waste forms at some time in the future.

4.1.1 High-Level Waste Vitrification

HLLW vitrification processes convert high-level liquid waste to an inert glass by the application of heat and the addition of glass-forming agents. A volume reduction factor of about 8 is achieved. Waste vitrification processes are well developed through laboratory and pilot-plant stages.

4.1.4

4.1.1.1 HLLW Vittrification Process Alternatives

A number of different HLLW vittrification processes are under development for installation at reprocessing plants in various countries. These processes are described in detail in ERDA-76-43.⁽²⁾ Among them are:

- spray calcination/continuous melting (Germany)
- rotary kiln calcination/continuous melting (France)
- the HARVEST process (Great Britain)
- fluidized bed calcination/continuous melting (Russia)
- spray calcination/in-can melting and fluidized bed fed or direct liquid fed/continuous melting in a joule-heated ceramic melter (United States).

Potential reprocessors in the U.S. have indicated various preferences for the different processes being developed in this country. The vittrification process selected as the reference for this report is spray calcination/in-can melting, the U.S. process identified in ERDA-76-43 as the most well developed.⁽²⁾

4.1.1.2 HLLW Vittrification Facility Design Basis

The function of the waste vittrification facility (WVF) is to convert high-level liquid waste to glass sealed in canisters. The WVF is assumed to be built at the same time as the fuel reprocessing plant it serves and to be an integral part of that plant, sharing its ventilation system, utilities and services. The following bases were used for design of the facility:

- Process HLLW from 2000 MTHM/yr
- .6 m³ (150 gal) HLLW per MTHM
- 300 days facility operation/yr
- Peak design capacity = 1.5 x nominal design capacity = 5.7 m³ (1500 gal)/day

4.1.1.3 Waste Vittrification Facility Process

The reference vittrification process, spray calcination/in-can melting, was developed at Pacific Northwest Laboratory (PNL). This study assumes that the HLLW undergoes solidification as it is generated by the reprocessing of fuel 1-1/2 years after discharge from a nuclear power plant. Options exist for solidifying wastes cooled for longer periods; the spent fuel may be stored longer before reprocessing (as described in Section 5.7), or the HLLW may be stored as a liquid for up to 5 years (as described in Section 5.1). The flowsheet consists of four steps: 1) calcination, 2) vittrification, 3) canister handling, and 4) effluent treatment. Figure 4.1.1 is a flow diagram illustrating these steps. Table 4.1.3 gives the radioactivity in the feed to the process. Table 4.1.4 describes the product from the process. The product is glass contained in a stainless steel canister. The leach rate of the glass is dependent on leaching conditions and upon glass composition. Over the long term a conservative estimate of leaching effects can be obtained by assuming uniform leaching of all constituents at the rate given in the table, 1×10^{-5} g of glass/cm²-day.

Calcination. The spray calciner decomposes the chemicals in the HLLW to a metal oxide calcine suitable for making waste glass and a process off-gas. The HLLW in the calciner feed tank is maintained at a temperature $\leq 40^{\circ}\text{C}$. From the feed tank, the HLLW is pumped at a controlled

4.1.5

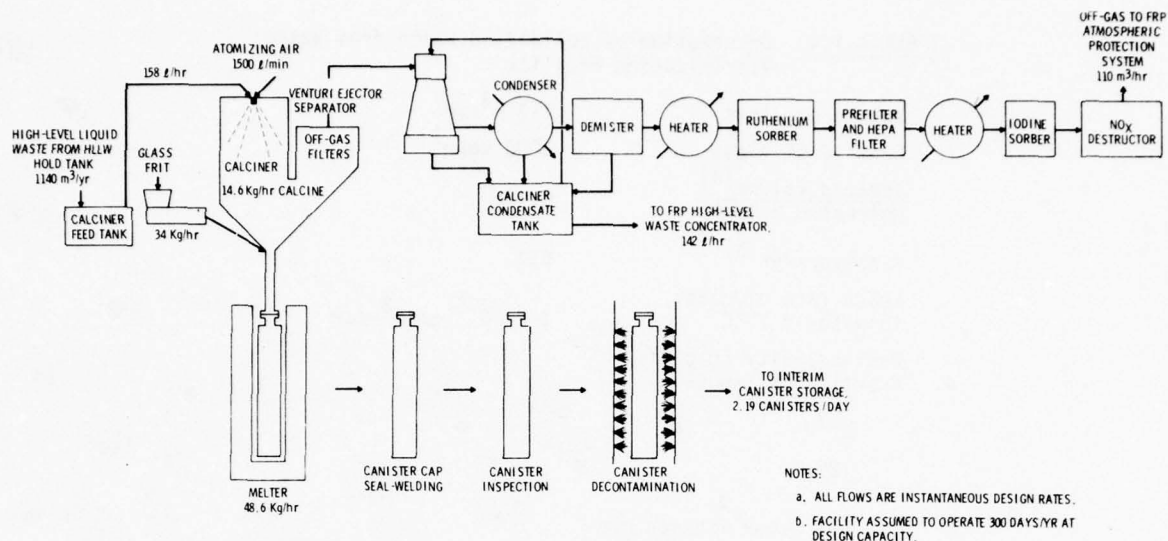


FIGURE 4.1.1. High-Level Liquid Waste Vitrifification System Flowsheet

TABLE 4.1.3. Activity in Untreated HLW^(a,b)

Component	Ci/year
Fission Products	
^3H	6.7×10^4
^{129}I	3.5×10^{-1}
$^{90}\text{Sr} + ^{90}\text{Y}$	2.4×10^8
$^{95}\text{Zr} + ^{95}\text{Nb}$	2.2×10^7
$^{106}\text{Ru} + ^{106}\text{Rh}$	7.6×10^8
$^{134}\text{Cs} + ^{137}\text{Cs} + ^{137\text{m}}\text{Ba}$	6.0×10^8
$^{144}\text{Ce} + ^{144}\text{Pr}$	9.6×10^8
All other fission products	2.0×10^8
Total	2.8×10^9
Actinides	
^{239}Pu	3.6×10^3
^{241}Pu	1.8×10^6
Other Pu	6.0×10^4
$^{244}\text{Cm} + ^{244}\text{Cm}$	3.4×10^7
All other actinides	2.0×10^6
Total	3.8×10^7

a. Based on waste characterization Table 3.3.29 assuming uranium and plutonium recycle, 2000 MTHM/yr reprocessed 1.5 yr out-of-reactor.

b. Volume = 1140 m³/yr.

4.1.6

TABLE 4.1.4. Description of Solidified Waste from Waste
Vitrification Facility

Volume of glass	117 m ³ /yr
Density of glass	3000 kg/m ³
$\frac{\text{Treated volume}^{(a)}}{\text{Untreated volume}}$	0.128
Canisters/yr ^(b)	657
Leach rate of glass in water @ 25°C	1×10^{-5} g/cm ² -day
Radioactivity in glass, fraction of input ^(c) :	
³ H	0
¹²⁹ I	0
All other fission pro- ducts and actinides	1.0

a. Treated volume based on canister volume with
canisters 80% filled.

b. 30 cm dia x 3 m long.

c. See Table 4.1.3.

rate to the calciner through a pneumatic atomizing spray nozzle. The temperature of the calciner walls is maintained at about 700°C by a multizone furnace. The waste solution is dried then converted to oxides and reaction gases, which include H₂O, HNO₃, and NO_x.

The calciner off-gas (at about 350°C) is filtered by sintered stainless steel filters to remove entrained calcine. Only about 0.1 wt% of the calcine passes through the filters; <2% of the ruthenium is volatilized and escapes the calciner. All iodine and tritium reaching the calciner also escapes into the off-gas. The balance of the radionuclides remain in the calcine, which falls through the cone at the bottom of the calciner into the canister where it is melted to form glass. The filters are periodically blown back with air to remove the calcine that accumulates on the filters and to allow it to fall through the cone into the canister.

Glass frit is metered into the calciner cone at a rate proportional to the HLLW feed rate. The flowsheet shown in Figure 4.1.1 uses a frit:calcine weight ratio of 2.33:1. The frit is a specially-formulated borosilicate glass powder. The frit granules are nominally 0.1-0.2 cm in diameter.

Vitrification. The in-can melter melts the calcine-frit mixture into a glass, using the canister contained in the retort of the melter furnace as the melting crucible. The calcine-frit mixture flows into the canister at a rate which does not exceed the melting rate. The mixture melts at about 1050°C. Once the mixture has been melted to a glass, the heating is terminated and cooling air is blown on the outer retort wall, thus cooling the wall and the canister to ≤900°C. The small volume of gas generated during the melting is routed to the calciner.

The retort may be filled with an inert gas, such as argon, to control spalling of the stainless steel canister during filling. Any spalled material is collected in a pan in the retort bottom and is removed for disposal as necessary.

4.1.7

Canister Handling. The filled canister is removed from the calciner connections, and the lid is placed on the canister. A prepackaged helium source may be placed in the canister prior to closure for later leak testing. Then, the filled canister is moved on to seal welding and inspection. The time cycle for canister filling and related operations is shown in Table 4.1.5.

TABLE 4.1.5. Time Cycle for Canister Operations

<u>Operation</u>	<u>Time, hr</u>
Place in melter; move under calciner; connect	1
Heat empty can	2
Fill	11
Top and allow bubble release	4
Cool	2
Disconnect; move away from calciner; remove from melter	1
Contingency	<u>1</u>
Total	22

The filled canisters are decontaminated with water and/or steam sprays to remove loose radioactive particles such as calcine. This solution is accumulated in a tank and periodically jetted to another tank for combination with HLLW prior to concentration.

Effluent Treatment. The waste vitrification process directly generates four kinds of effluents: calciner off-gas, canister decontamination solution, canister cooling air, and canister cover gas. In addition, there are effluents from the processing area, including cell ventilation air, vessel ventilation air, and cell decontamination solutions.

The calciner off-gas, after passing through the sintered stainless steel filters, is subjected to the following process operations to remove particulate radionuclides, gaseous radionuclides, and NO_x :

- quenching
- condensing
- mist elimination
- ruthenium sorption
- filtration
- iodine sorption
- NO_x destruction.

These steps are taken prior to releasing the calciner off-gas to the atmospheric protection system (APS).

4.1.8

The canister cooling air, canister cover gas, and cell ventilation air are combined and filtered through the cell air filtration system to remove radioactive particles prior to release to the FRP APS. The cell air filtration system includes 1 stage of roughing filters followed by 2 stages of HEPA filters. The filter installations are periodically tested to insure their continued efficiency. The WVF vessel ventilation air is routed to the FRP vessel off-gas system.

The canisters are routinely decontaminated with high pressure water. Periodically some cell or equipment decontamination will also be required. Decontaminating agents used may include steam, water, nitric acid, caustic, potassium permanganate, and tartaric acid. The decontamination solutions will be collected in the cell sump or other tanks and jetted to the decontamination waste accumulation tank for sampling. They will then be combined with the HLLW or routed for separate treatment as intermediate-level liquid waste (ILLW).

Optional Processing Mode: Combining ILLW with HLLW. Combining ILLW with HLLW prior to solidification is a very feasible operating mode for the reprocessing plant. This method has, in fact, been selected as the solidification method for ILLW by AGNS and Exxon in their reprocessing plant flowsheets. ILLW is a composite waste of variable composition.⁽²⁾ It may contain many, or all, of the following:

- laboratory liquid wastes, including samples and reagents
- solvent wash wastes, including entrained and degraded solvent
- off-gas scrubber residues
- iodine scrubber residues
- fuel receiving and storage liquid wastes, including ion-exchange regeneration wastes, cask decontamination wastes, and cask cool-down system wastes
- solvent burner quench pot scrubber solutions
- building and equipment decontamination wastes
- building floor drainage
- liquid waste from personnel decontamination facilities
- cold chemical wastes from the cold chemical makeup area.

As generated, ILLW has a typical acidity of 2.5 M H^+ . The reference ILLW (see Section 3.3, Table 3.3.31) is assumed to have been neutralized in preparation for non-high-level immobilization processing. If the ILLW were to be combined with HLLW it would not be neutralized. Unneutralized, the reference ILLW would add 18 kg of waste oxide/MTHM to the WVF feed stream. This would increase the total volume of glass produced by 34%; about 65 kg of glass would have to be melted each hour to accommodate the additional waste.

In order to achieve this higher melting rate, the canister diameter would be increased to 40 cm (16 in). The reference HLW management system defined for this report is based on a maximum HLW canister diameter of 30 cm (12 in.), and the ILLW is solidified separately

4.1.9

from HLLW (see Section 4.7). It should also be noted that since ILLW is a composite waste there is some chance that chemicals incompatible with vitrification could be in the ILLW if suitable precautions were not observed. Among such incompatible chemicals are halogens and mercury. Halogens would be volatilized and quickly saturate the iodine adsorber. Mercury would also be volatilized; special mercury recovery equipment would have to be installed to collect condensed mercury in the off-gas system.

4.1.1.4 Waste Vitrification Facility Description

The reference WVF is assumed to have been constructed at the same time as the fuel reprocessing plant it serves and to be an integral part of that plant, sharing its ventilation system, utilities and services. The approximate location of the WVF in the fuel reprocessing plant is shown in Figure 4.1.2.

The WVF uses a single cell to perform calcination, vitrification, canister handling, and limited effluent treatment. Some associated operating and service areas are partially included in the following description. Facilities related to utilities, maintenance, air supply, final effluent treatment, personnel support, and other services that are part of the FRP as a whole are not described here. They are identified, however, as they pertain to the WVF, so they can be properly accounted for in the system requirements.

Waste Vitrification Cell. The waste vitrification cell (WVC) is a reinforced concrete structure with interior dimensions of 8.5 m (28 ft) wide x 10.7 m (35 ft) long x 16.8 m (55 ft) high. The cell walls are 1.8 m (6 ft) thick to reduce the radiation dose rate at the outer wall to ≤ 1 mrem/hr. The cell is lined with stainless steel 5 mm (3/16 in) thick, to assist in cell decontamination and decommissioning. The lining will also protect the cell walls from corrosive chemicals and vapors.

The cell layout, some of the associated facilities, and the operating galleries are shown in Figures 4.1.3 through 4.1.8. Four shielding windows are provided for viewing and guiding the operations within the cell. There are penetrations in the cell wall for service equipment such as master-slave manipulators, periscopes, two melter umbilical pipes, cell monitoring instrumentation, and equipment operation instrumentation. Service piping from the hot pipe trench to the adjacent cell remote heads is cut into the cell wall. Service piping from the hot pipe trench or cold side to the cell side walls is routed through recesses in the cell wall behind the cell liner. There is also a sump on the cell floor under the liner that drains to a cell sump header. Most cell equipment is designed for remote removal, to facilitate maintenance. The crane moves on rails built as part of the cell walls. The melters move on rails mounted on the cell floor. Some empty floor space is left in the cell to accommodate any additional canister test equipment that may be required by Federal waste acceptance criteria.

The main equipment access to the cell is through the shielding doors leading to the hot maintenance area (HMA). The doors seal when closed to minimize air in-leakage from the HMA. A second equipment access is through the canister decontamination cubicle (CDC). Through this

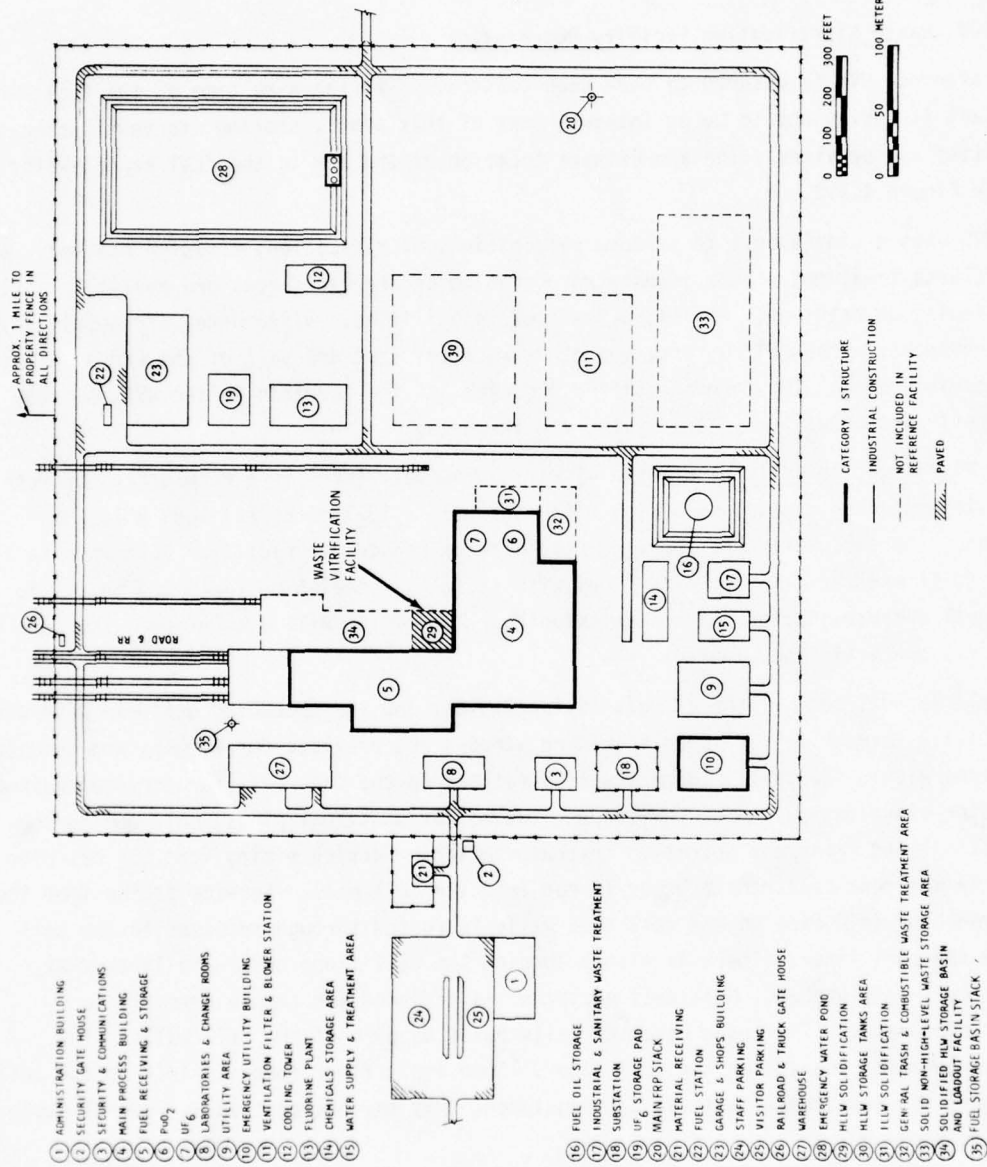


FIGURE 4.1.2. Location of Waste Vitrification Facility Within the Reference Fuel Reprocessing Plant

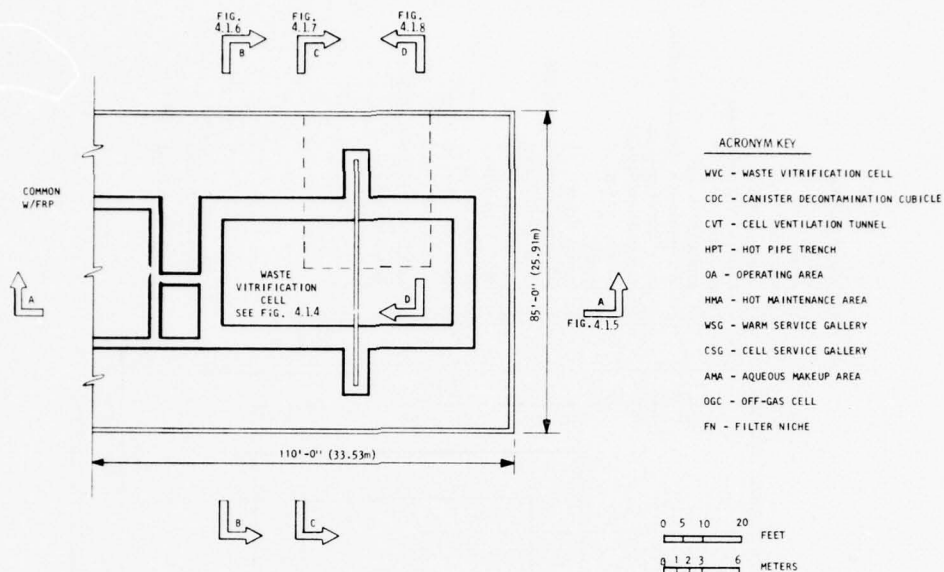


FIGURE 4.1.3. Waste Vitrification Process Key Plan

cubicle, empty and full canisters are moved into or out of the cell. Full canisters are decontaminated upon removal from the cell. The cover between the cubicle and the vitrification cell is airtight. After the canisters are spray decontaminated and water rinsed, they are submerged in cooling water. They are then picked up remotely with the CDC bridge crane and moved into the canister transfer canal. The canisters are lowered onto an underwater, motor-driven transfer dolly for transport along the canal into the adjacent water basin storage area (See Section 5.4). transport along the canal into the adjacent water basin storage area (See Section 5.4).

Ventilation air will be supplied to the WVC by small amounts of air leaking into the cell and by a filtered air supply.

Major Equipment. The spray calciner, in-can melter, and canisters are among the equipment items specially designed for the WVF. Other major equipment items, with less unique design features, include the welding and inspection station, the liquid feed system, the frit-feeder and the components of the off-gas system.

Spray Calciner. The spray calciner, shown in Figure 4.1.9, has a liquid feed capacity of 24-240 ℓ /hr. The calciner chamber is a right cylinder 0.9 m in dia and 3 m high that is heated through the wall with a 280 kW electrical furnace. The normal operating temperature for the calciner is 700°C, maximum operating temperature is 1000°C. Liquid waste is sprayed into the calciner as droplets less than 80 μ m in dia through a pneumatic atomizing nozzle with a 0.6-cm ID orifice.

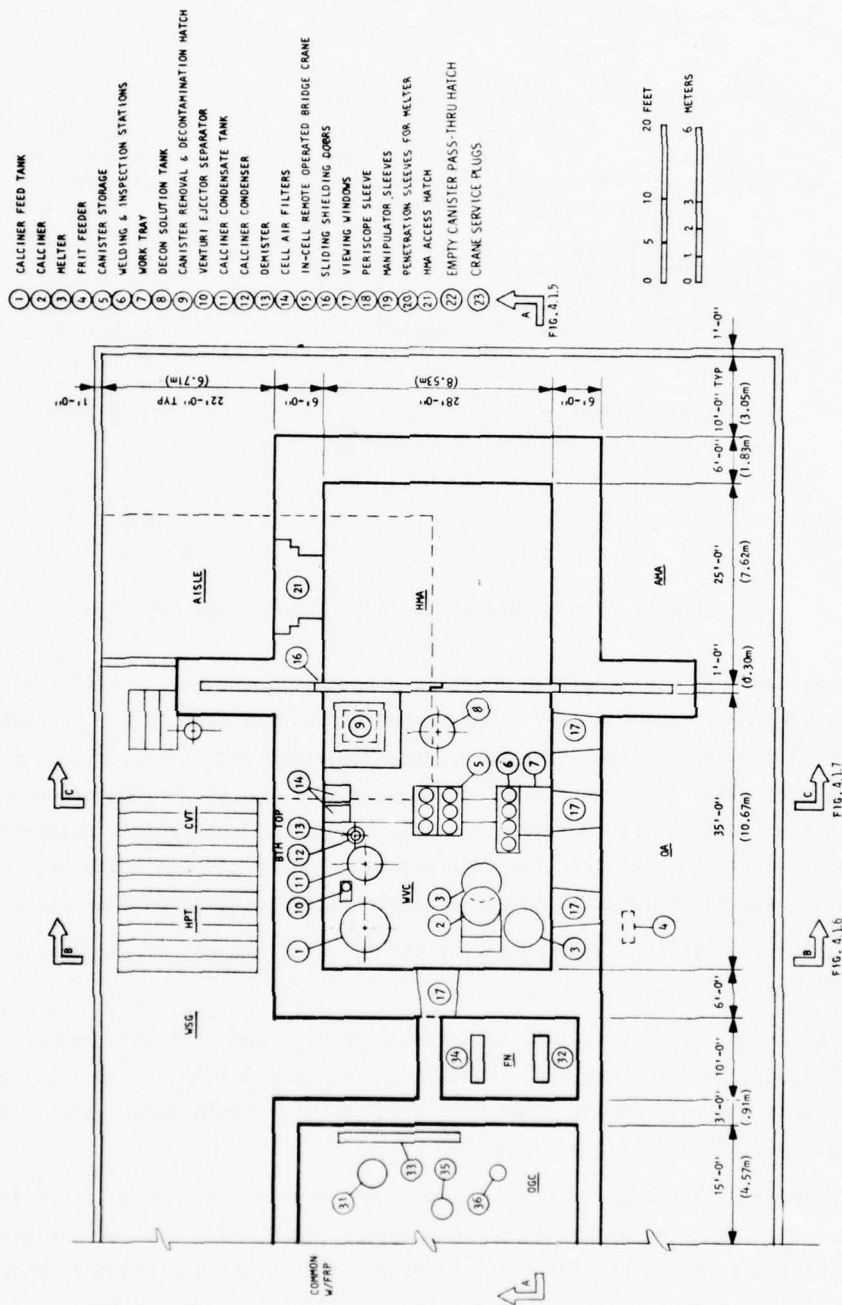


FIGURE 4.1.4. Waste Vittrification Process Equipment Arrangement (See Figure 4.1.3 for acronym key.)

4.1.13

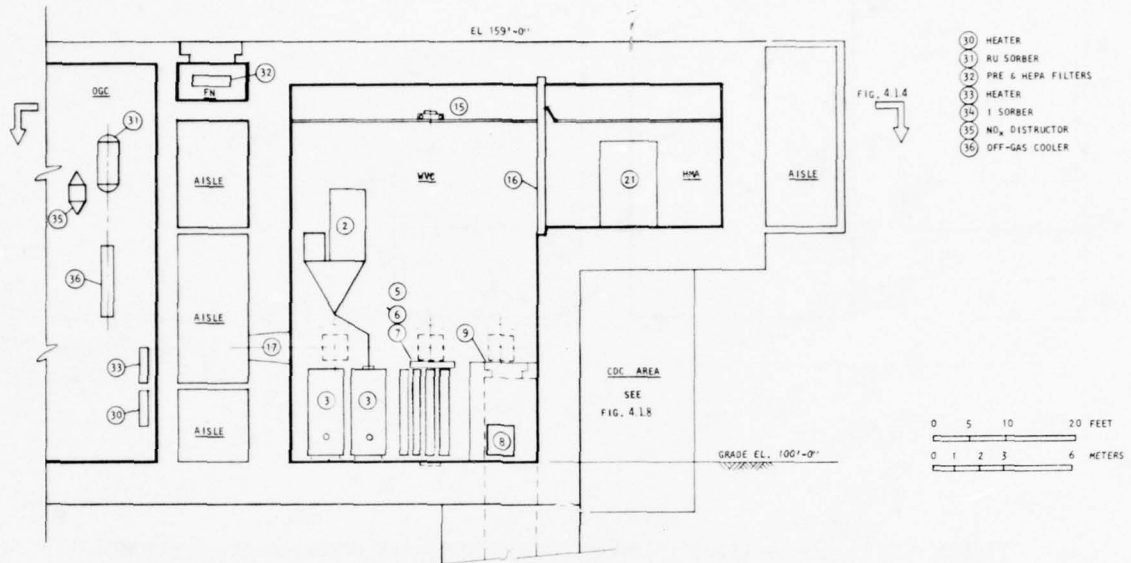


FIGURE 4.1.5. Waste Vitrification Process Equipment Arrangement, Section A-A
(See Figure 4.1.3 for acronym key and Figure 4.1.4 for key to circled numbers.)

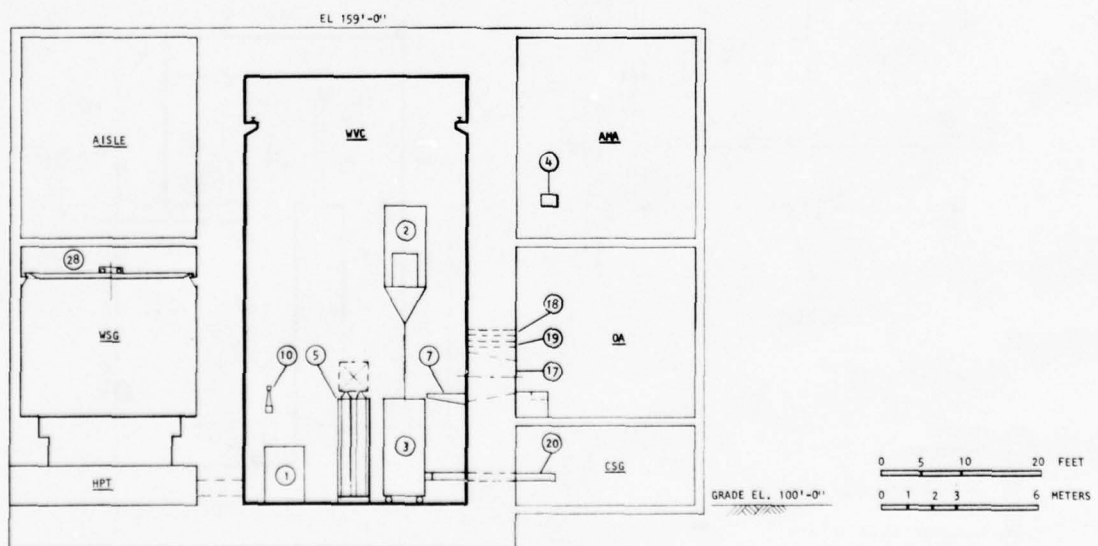


FIGURE 4.1.6. Waste Vitrification Process Equipment Arrangement, Section B-B
(See Figure 4.1.3 for acronym key and Figure 4.1.4 for key to circled numbers.)

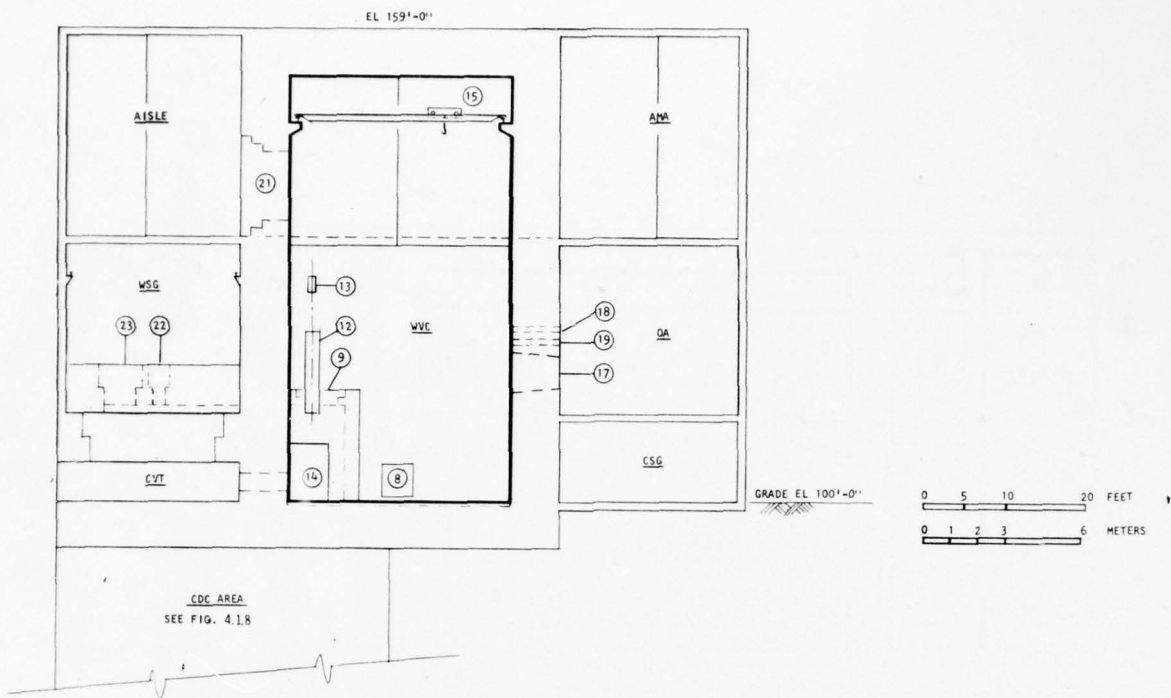


FIGURE 4.1.7. Waste Vitrification Process Equipment Arrangement, Section C-C
(See Figure 4.1.3 for acronym key and Figure 4.1.4 for key to circled numbers.)

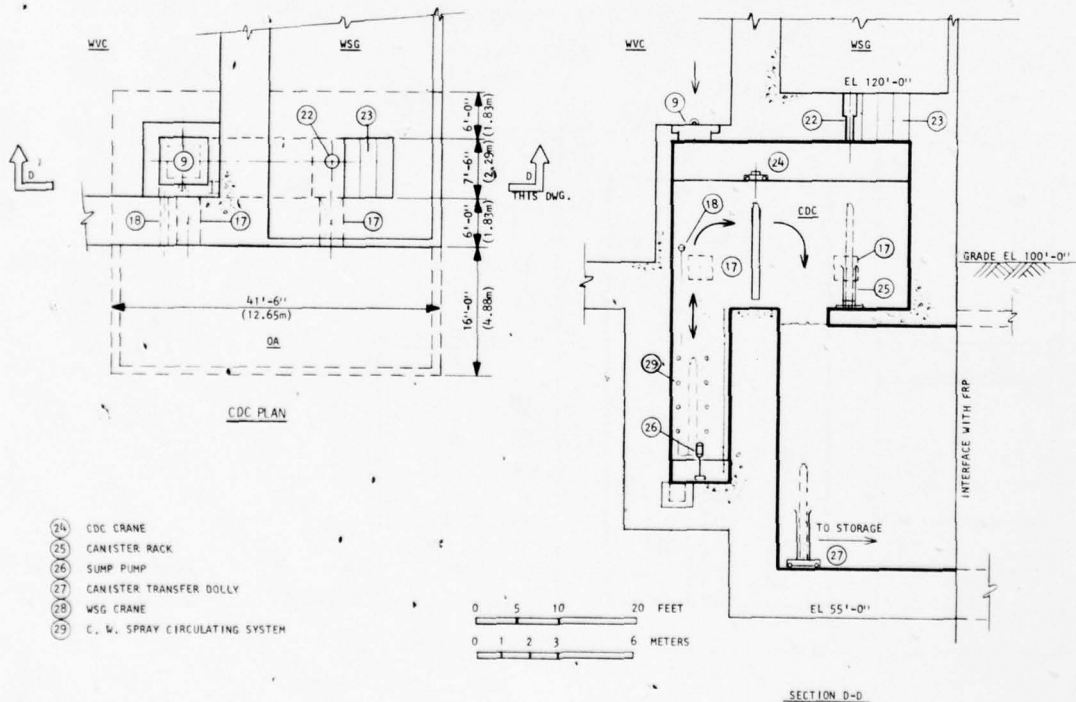


FIGURE 4.1.8. Waste Vitrification Process Equipment Arrangement, CDC Plan and Section D-D
(See Figure 4.1.3 for acronym key and Figure 4.1.4 for key to part numbers 1 through 23.)

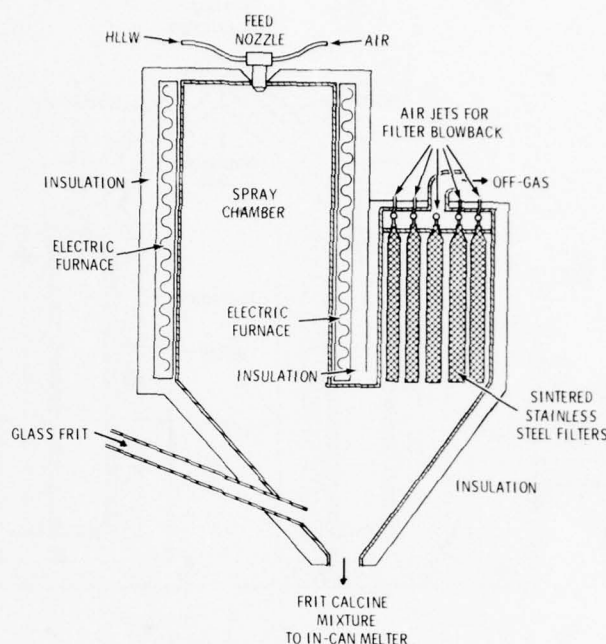


FIGURE 4.1.9. Spray Calciner

Off-gas is filtered through a bank of sintered stainless steel filter candles having a total filtration area of 14 m^2 . The filters can be blown back intermittently with short pulses of air to remove filter cake. Of the 70 filter candles, 14 are blown back simultaneously.

A frit feed line enters near the bottom of the calciner cone so that some premixing of the calcine and glass frit can occur before entering the in-can melter, which is located directly beneath the calciner.

In-Can Melter. Figure 4.1.10 shows the in-can melter used in the WVF. Two such melters are connected to the spray calciner by a diversion valve, so that one canister can be removed while the other canister is being filled. The in-can melter uses an 8-zone furnace with a heated chamber 3.25 m long. The power to each zone (maximum $\approx 30 \text{ kW}$) can be controlled independently. Each zone can also be air-cooled independently. The normal operating temperature for the in-can melter is 1050°C ; maximum operating temperature is 1200°C . Nominal glass melting capacity of the in-can melter is 50 kg/hr .

Melter off-gas exits through the coupling section and is combined with the calciner off-gas. The coupling section must have a minimum slope of 60° from the horizontal and its temperature must be maintained above 100°C to prevent deposition of the incoming frit-calcine mixture in the coupling section.

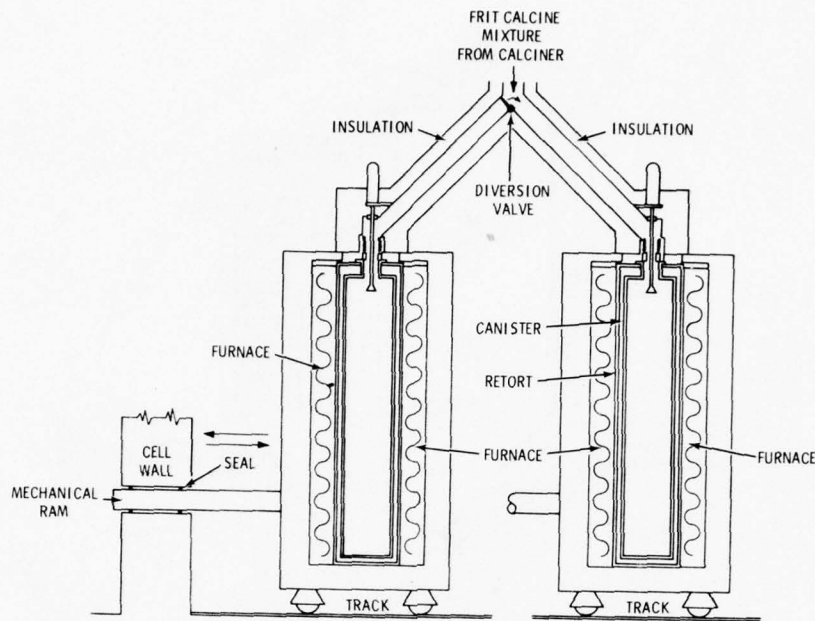


FIGURE 4.1.10. In-Can Melter

The furnace is fitted with a liner, or retort, that protects the furnace in the event molten glass leaks from a canister. If an inert gas blanket is used to control external oxidation of the canister, the retort also serves to contain this blanket around the canister.

Both in-can melters are mounted on tracks so that they can be moved from beneath the calciner. Before moving a furnace the valve in the inlet is retracted to form a seal which minimizes release of calcine to the cell atmosphere during canister removal. The waste canisters are removed from the furnace and moved around the WVC by an overhead crane.

HLW Canister. Figure 4.1.11 shows the canister in which the waste glass is melted. After melting is completed the canister becomes the storage container for the waste glass. The design is conceptual for the purposes of this report. Actual waste canisters may be expected to differ in certain details.

The canister is 30 cm in dia (12 in schedule 40 pipe) and 3 m long. All canister materials are assumed to be 304L stainless steel. Eight longitudinal internal fins are provided to conduct heat into the canister to increase the melting rate during processing; they also assist in cooling the glass after the canister is filled. The fin assembly rests freely inside the canister and is not attached to the canister wall.

Each canister is seal welded after filling. After seal welding the canisters are fitted with a standardized remote grapple fitting to facilitate handling through subsequent stages of HLW management. During shipping a special collar is placed around the grapple fitting so that it does not act as a projectile point if the shipping cask is stopped abruptly.

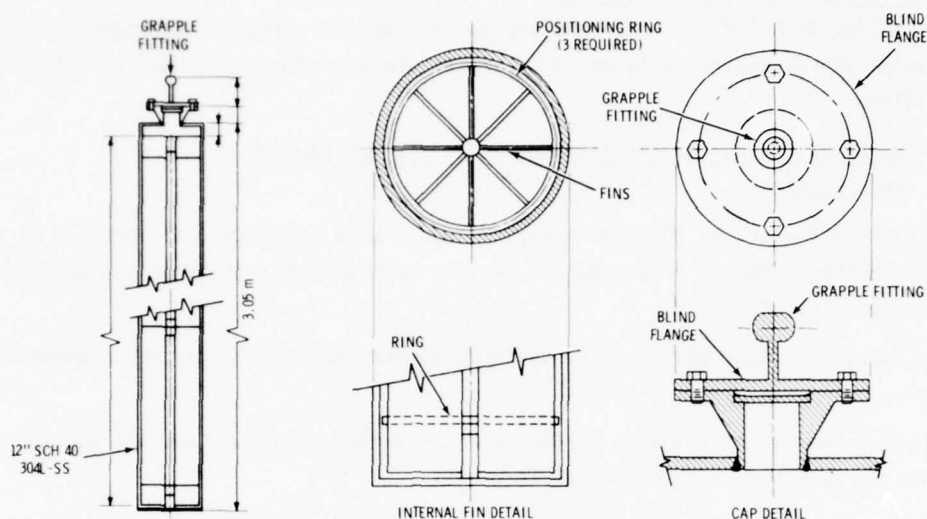


FIGURE 4.1.11. Canister for Containment of Vitrified Waste

Welding and Inspection Station. Seal welding of the canisters is done in an automated station in the WVC. Canisters are moved sequentially through the station on a track. At the first stop in the station the seal plate is welded using a tungsten inert gas welder. The welding torch is mounted on a jig containing a variable speed drive that automatically rotates the torch around the circumference of the weld. The next stop in the station is for checking the integrity of the seal weld. Several techniques are applicable here, ranging from dye penetrant examination to helium mass spectrometer leak detection.

Liquid Feed System. The feed tank for the spray calciner is located in the WVC and has a capacity of 4500 l. HLLW is recirculated from the feed tank through a loop by a high capacity cantilever pump to assure uniform suspension of any solids which may be present. The feed to the spray calciner is taken at a controlled rate as a side stream from the recirculating loop.

Frit Feeder. The frit feeder is located outside the WVC and feeds through an air lock combination of valves into the cell and to the spray calciner. The glass frit, which has a -20 + 80 mesh particle size, can be metered with commercially available vibratory or screw-type solids feeders.

Off-Gas System Components. The off-gas system components were shown as part of the flow diagram in Figure 4.1.1. The first component, a venturi scrubber-separator, is used to remove particulate entrainment for recycle. A prefilter and two HEPA filters in series are also provided to remove particles. Special sorbers are provided for volatile ruthenium and iodine. Silica gel is used as the ruthenium sorbent and silver zeolite as the iodine sorbent. The silica gel bed can be regenerated; the silver zeolite bed cannot be regenerated and will be replaced about every 5 years.

Shielding and Remote Handling Equipment. The WVF is designed for complete remote operation and is shielded with 1.8 m (6-ft) concrete walls. Master-slave manipulators, electro-mechanical manipulators, and remotely operated cranes are used for all normal activities and equipment handling.

4.1.1.5 Waste Vitrification Facility Operating and Maintenance Requirements

The reference WVF operates 24 hours a day, 7 days a week. Startup and shutdown of the facility can be accomplished in a few hours. Certain maintenance activities are performed periodically; these include:

- removing calciner condensate from the calciner condensate tank to the HLLW concentrator feed tank
- changing decontamination solution in the decontamination solution tank and routing the used solution to the HLLW concentrator feed tank
- jetting the sump solutions to a waste collection tank for sampling
- regenerating the ruthenium sorber with dilute nitric acid or hot water, which is routed to the HLLW concentrator feed tank
- decontaminating equipment by flushing, and routing the decontamination solution to the HLLW concentrator feed tank
- repairing occasional seal weld leaks or overpacking an off-standard canister
- flushing a calciner seal pot to the HLLW concentrator feed tank and filling it with water.

Maintenance requirements for the WVF are characteristic of fully-remote, high-radiation operations. Maintenance or replacement of equipment in this type of operation is about an order of magnitude more time consuming than for hands-on operated equipment; equipment reliability is, therefore, a prime consideration in the design of the WVF.

In-cell equipment is designed for simplicity of operation and maintenance. To aid in remote operations, equipment is arranged to permit unobstructed crane access and is fitted with lifting devices (lugs, yokes, etc.). The use of equipment with moving parts subject to high maintenance frequency is minimized. All equipment is designed and selected on the basis of suitability for extended use and high reliability. Major pieces of process equipment are made of materials exhibiting high resistance to corrosion, radiation damage, and process operating conditions. Similarly, all of the equipment, piping, and instrument tubing in radioactive areas are made to withstand decontamination solutions.

Staffing. The WVF staffing requirements are shown in Table 4.1.6.

TABLE 4.1.6. Waste Vittrification Facility
Staffing Requirements

<u>Job Description</u>	<u>Personnel Required, man-yr/yr</u>
Operators	19
Radiation monitors	1
Maintenance craftsmen	9

Supplies and Utilities. Table 4.1.7 shows the materials for operating the WVF. Chemicals used for periodic facility decontamination and cleanup are included. Table 4.1.8 gives power, water, air and steam requirements.

TABLE 4.1.7. Waste Vittrification Facility
Supply Requirements

<u>Supply</u>	<u>Use</u>	<u>Annual Requirement</u>
Glass frit	Waste immobilization media	2.5×10^5 kg
Canisters	Containment of solidified waste during storage, shipping, and disposal	660 canisters
Caustic (19 M)	In-cell decontamination	8 m^3
Nitric acid (12.2 M)	In-cell decontamination	12 m^3
Helium sources ^(a)	Leak check of canister seal welds	750 sources
Argon ^(a)	Inert gas blanket for canisters in in-can melter	$1300 - 1700 \text{ m}^3$
Detergent	In-cell decontamination	225 kg
Ammonia	Reactant in NO_x destructor	1.2×10^5 kg
Silver Zeolite	Iodine adsorber	

a. Optional

TABLE 4.1.8. Waste Vittrification Facility Utility
Requirements

<u>Utility</u>	<u>Use Rate</u>	<u>Annual Requirement</u>
Electricity	566 kW	4×10^6 kWh
Water Consumed	$9.7 \text{ m}^3/\text{day}$	2900 m^3
Steam	80 kg/hr	5.8×10^5 kg

4.1.1.6 Waste Vitrification Facility Secondary Radioactive Wastes

Table 4.1.9 gives the secondary radioactive wastes produced by the WVF. These wastes are routed back into the FRP for treatment. Failed equipment and solid trash from the WVF have no unique characteristics that require special treatment and are disposed via FRP facilities for those types of wastes. Liquid secondary radioactive wastes are recycled to the FRP high-level waste concentrator.

TABLE 4.1.9. Waste Vitrification Facility Secondary Radioactive Wastes

Description	Volume, m ³ /yr	Radioactivity Factor ^(a)
Combustible and compactable waste	100	2×10^{-7}
Failed equipment and noncombustible trash	50	6×10^{-6}

a. Fraction of input activity (Table 4.1.3) in secondary wastes.

4.1.1.7 Waste Vitrification Facility Emissions

Air and water constitute WVF emissions ultimately released to the environment. The air from the process equipment and the cell ventilation is radioactive. The properties of those air streams and their activity are shown in Table 4.1.10. Table 4.1.11 lists the decontamination factors (DF) assumed for each of the components of the in-cell off-gas train. The off-gas then passes through the FRP APS where an additional 10^4 DF for particulates is obtained.

An estimate of the integrated annual release due to minor accidents (Section 4.1.1.9) for this facility is included in Table 4.1.10. It was developed by weighing the minor accident releases by their expected frequencies and summing the quantities for all identified minor accidents. In addition, a contingency was included in the integrated release to account for unidentified minor accidents and to compensate for the uncertainty in expected frequency information. Estimated integrated annual releases due to minor accidents for this technology is shown in Table 4.1.10.

There are no other significant emissions from the WVF. There are no obnoxious noises, odors, or vibrations associated with its operation.

4.1.1.8 Waste Vitrification Facility Decommissioning Considerations

The useful life of the WVF is the same as that of the FRP, 30 years. Residual activity at the time of decommissioning is estimated to be about 1×10^5 Ci after removal of the ruthenium and iodine sorbers. Much of the activity will be associated with fine powdery calcine on the cell walls and floor and will be easily removed during decontamination. After decontamination, the activity remaining in the WVF should be less than 10^3 Ci.

TABLE 4.1.10. Waste Vitrification Facility Emissions

Emission	Description	Annual Quantity	Radioactivity Release Factor to Atmosphere ^(a)
Gaseous	Process off-gas, ventilation air, and vaporized excess water	$1.2 \times 10^8 \text{ m}^3$	${}^{129}\text{I}$ 1.0 ${}^{137}\text{Cs}$ 1×10^{-3} Ru 1×10^{-10} All others 2×10^{-15}
	Minor accident integrated annual release		All 1×10^{-17}
	Ammonia ^(b)	$1 \times 10^4 \text{ kg}$	
Cooling tower water	• evaporated, $T = 38^\circ\text{C}$	$2.5 \times 10^6 \text{ kg}$	
	• drift, $T = 38^\circ\text{C}$	$1.2 \times 10^4 \text{ kg}$	
	• blowdown, $T = 27^\circ\text{C}$	$4.3 \times 10^5 \text{ kg}$	
Other	Heat	$1.7 \times 10^3 \text{ MW-hr}$	
		$(5.7 \times 10^9 \text{ BTU})$	

a. Fraction of input activity (Table 4.1.3) released to atmosphere. Includes DF from main plant APS where applicable. Released over 300 days/yr.

b. From the NO_x destructor.

TABLE 4.1.11. Estimated Decontamination Factors for Off-Gas Cleanup in the Waste Vitrification Facility

Equipment	Estimated DF ^(a)			
	Iodine	Ruthenium	Particles	NO_x
Calciner and filter	1	10	200	
Venturi scrubber, condenser and demister	1	10	10	1
Ruthenium adsorber	1	10^3	2	1
HEPA filter bank (roughing + 2 HEPAs)	1	10	10^7	1
Iodine sorber	10^3	1	1	1
NO_x converter	1	1	1	100
Overall facility DF	10^3	10^6	4×10^{10}	100

a. DF = ratio of the activity entering the equipment to the activity leaving facility.

4.1.1.9 Waste Vitrification Facility Postulated Accidents

Postulated minor and moderate accident scenarios for the WVF are presented in Tables 4.1.12 and 4.1.13. The consequence of most of the accidents is the release of no more than a few grams of airborne calcine to the cell atmosphere. Each metric ton of spent fuel processed yields 52.5 kg of HLW calcine. The WVF cell ventilation air leaves the cell through a roughing filter and two HEPA filters ($\text{DF} = 10^7$). The cell ventilation air is then combined with the FRP HVAC air before going through the atmospheric protection system ($\text{DF} = 10^4$). Thus, the decontamination factor for calcine particles is 10^{11} before release at the FRP stack.

TABLE 4.1.12. Waste Vitrification Facility Minor Accidents

Accident No. and Description	Sequence of Events	Safety Systems	Release
4.1.1-Hydrogen explosion in feed tank. Expected frequency $\sim 0.01/\text{yr}$.	<ol style="list-style-type: none"> 1. Extended undetected loss of air purge allows hydrogen accumulation. 2. Ignition source causes hydrogen explosion. 3. Repair or replace equipment as required. 	<ol style="list-style-type: none"> 1. Multiple air purges with flow indicators. 2. Designed to eliminate ignition sources. 	None. Solution safely contained in floor pan.
4.1.2-HLLW feed system leakage. Expected frequency $\sim 0.1/\text{yr}$.	<ol style="list-style-type: none"> 1. Leakage in pressurized line at fitting or connection. 2. Leakage detected. 3. Leaking equipment repaired. 	<ol style="list-style-type: none"> 1. Primarily welded connections. 2. Sump alarm enables early detection. 	None. Solution safely contained in floor pan.
4.1.3-Calcine spill due to backup in equipment or other process irregularity. Expected frequency $\sim 2/\text{yr}$.	<ol style="list-style-type: none"> 1. Calcine backup due to - bridging in melter - partial plugging in chute. 2. Maloperation of cone valve. 3. Disconnect canister and remove calcine blockage. 	<ol style="list-style-type: none"> 1. Vibrators on calciner to reduce holdup. 2. Bridging detector in melter. 	Nominally a few grams of calcine would be released to cell. In the worst case up to 2 kg calcine released to cell. Of this material 70% reaches the cell HEPAS resulting in a 1.5×10^{-5} mg release over 1 hour from the FRP stack.
4.1.4-Sintered metal filter failure. Expected frequency $\sim 0.1/\text{yr}$.	<ol style="list-style-type: none"> 1. Filter fails due to corrosion, mechanical shock or excessive temperature. 2. Filter replaced. 	<ol style="list-style-type: none"> 1. Designed to minimize need for replacement. 	None. <100 g of calcine may be dislodged during replacement. Precautions taken to prevent its becoming airborne.
4.1.5-Canister and retort failure during melting operation. Expected frequency $\sim 0.01/\text{yr}$.	<ol style="list-style-type: none"> 1. Furnace control failure and operator inattention. 2. Canister and retort failure release molten glass into furnace. 3. Replace furnace. 	<ol style="list-style-type: none"> 1. Multiple zone furnace with separate controls and alarms. 2. Redundant temperature readouts on each zone. 	None.

A few of the accidents affect equipment in the WVF off-gas treatment system. The duration of any of these accidents involving equipment failures in the off-gas system should not exceed 8 hours.

The most severe potential accident identified for this technology is a calciner rupture. This accident cannot be realistically postulated to occur during the design-life of the plant because several unlikely independent events are required for its initiation. For this reason, the calciner rupture accident was placed in the non-design basis category (See Section 3.7) and is not described here. Even if this accident occurred, release of calcine to the cell filters would be less than in accident 4.1.3. Calciner failure due to overheating is another accident in the non-design basis category. This accident would also release calcine to the cell atmosphere, but the amount released should be less than in the calciner rupture accident.

TABLE 4.1.13. Waste Vittrification Facility Moderate Accidents

Accident No. and Description	Sequence of Events	Safety Systems	Release
4.1.6-Feed solution backup in air line or contamination spread to occupied zones. Expected frequency ~0.2/yr.	<ol style="list-style-type: none"> 1. Feed nozzle plugs. 2. Atomizing air check valve fails allowing airline to fill with HLLW. 3. Empty and decontaminate the line. 	<ol style="list-style-type: none"> 1. Multiple detection systems. 2. Air supply pressure exceeds feed pressure. 	None. 100 g HLLW backs up in an air line. This presents a line source 1 m long exposing 2 persons 1 m away for up to 10 minutes.
4.1.7-Off-gas iodine or ruthenium adsorber malfunction. Expected frequency ~0.1/yr.	<ol style="list-style-type: none"> 1. Exhaustion or degradation of sorbent or bed channeling. 2. Adsorber malfunction detected. 3. Replace adsorbent with trash adsorbent. 	<ol style="list-style-type: none"> 1. Substantial bed depth used to assure sorptive capacity and minimize channeling. 2. In-line monitoring equipment. 	<100-fold increase in I-129 activity or <10-fold increase in Ru-106 activity in WVF process off-gas to FRP atmospheric protection system, from malfunction of iodine or ruthenium adsorber, respectively.
4.1.8-Process off-gas filter failure. Expected frequency ~0.2/yr.	<ol style="list-style-type: none"> 1. Filter fails. 2. Failure detected and off-gas diverted to spare filter bank. 3. Filter replaced. 	<ol style="list-style-type: none"> 1. Differential pressure and radiation instrumentation. 2. Spare filter bank. 	1×10^{-3} g of calcine released from the FRP stack over 1/2 hour.
4.1.9-Off-gas blower failure. Expected frequency ~0.1/yr.	<ol style="list-style-type: none"> 1. Mechanical failure or loss of electrical power. 2. Alternate blower or power system activates. 	<ol style="list-style-type: none"> 1. In-line spare blower. 2. Off-gas blowers on emergency power. 	None. Fraction of gram of calcine dust may become airborne, but all contained in cell.
4.1.10-Failure of cell exhaust filters. Expected frequency ~0.1/yr.	<ol style="list-style-type: none"> 1. Filters not properly sealed, or damaged during handling of filter or process equipment, or moisture buildup. 2. Defective filters replaced. 	<ol style="list-style-type: none"> 1. Periodic test of filters' efficiencies. 	Slight increase in activity of cell off-gas to FRP atmospheric protection system.

For purposes of environmental consequence analysis, the material release associated with accidents numbered 4.1.3, 4.1.6 and 4.1.8 in Tables 4.1.12 and 4.1.13 have been selected as umbrella source terms. (The concept of an umbrella source term is explained in Section 3.7 - Basis for Accident Analysis.) This means that the releases from these accidents are the largest in their respective source term categories. Accidents are cross indexed with their appropriate umbrella source term in Appendix A, Section 3. The environmental consequences of these accidents are described in DOE/ET/0029.

The releases for the umbrella source terms were developed as follows: Accident 4.1.3 is representative of minor process failures which may result in leakage of a few grams of calcine to the cell. A very unlikely but potential worse case would be the spillage of 2.1 kg of calcine. Accident 4.1.6 represents accidents with potential nuclide release through penetrations of the cell shielding to occupied zones of the plant. The 10-minute exposure period is a conservative estimate of the maximum time for evacuation following an alarm. The upper limit for this type of accident is believed to be bounded by the back up of 100 g of HLLW in an air line. Material released in Accident 4.1.8 was assumed to be jarred loose from the filter media during filter failure. System shutdown following filter failure limits releases from this accident.

4.1.24

4.1.1.10 Waste Vitrification Facility Costs

Estimates have been made, in mid-1976 dollars, of capital, operating, and levelized unit costs for vitrification of high level waste. A complete description of cost estimate bases, assumptions, and definitions is given in Section 3.8.

Capital Costs. The capital cost estimate for the waste vitrification facility is shown in Table 4.1.14. The estimate covers all capital costs specifically resulting from including the WVF as an integral part of the reference FRP. These costs also include the effect of incremental additions to utility supplies, such as electrical substation, HVAC, compressed air, and similar auxiliaries, as well as the cable, piping and other bulk materials incorporated directly into the facility. However, general FRP costs for services such as laboratories, warehousing, shops, and offices are not allocated to the WVF.

The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation, with the exception of working capital and special maintenance equipment. HLW canisters, overpacks, and consumable process materials are included in operating costs. Shielding casks for failed equipment are included in transportation.

TABLE 4.1.14. Capital Cost Estimate for the Waste Vitrification Facility

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		50	3,900	600	4,500
Building and structures		520	2,800	6,300	9,100
Bulk materials		320	3,900	3,800	7,700
Site improvements		10	100	100	200
Subtotal of direct site construction costs		900	10,700	10,800	21,500
Indirect site construction costs	240	180	4,000	5,200	9,200
Total field cost	240	1,080	14,700	16,000	30,700
Architect-engineer services					5,500
Subtotal					36,200
Owner's cost					10,800
Total facility cost					47,000
Estimate accuracy range					±30%

Operating Costs. Table 4.1.15 tabulates the operating costs for the high-level waste vitrification facility. Direct labor costs were estimated using the manpower figures in Table 4.1.6 and the wage factors given in Section 3.8. In addition, the direct labor costs include an allowance of \$400,000 for major remote maintenance requirements. Process materials consist of 658 12-in. dia. x 10-ft. long stainless steel canisters at \$5,500 each. Utility costs are based on requirements shown in Table 4.1.8. Annual maintenance materials are estimated at 5% of major equipment plus \$45,000. Overhead and miscellaneous costs are estimated using the factors given in Section 3.8.

Levelized Unit Costs. The levelized unit cost, including levelized capital and operating segments, is given in Table 4.1.16. The unit cost calculation assumes private ownership of the facilities and a 15-year economic life.

TABLE 4.1.15. Operating Cost Estimate for the Waste Vitrification Facility

<u>Cost Element</u>	<u>Annual Costs, \$1000s</u>
Direct labor	840
Process materials	4000
Utilities	90
Maintenance materials	270
Overhead	660
Miscellaneous	<u>240</u>
Total	6100 $\pm 25\%$

TABLE 4.1.16. Levelized Unit Cost Estimate for the Waste Vitrification Facility

<u>Cost Element</u>	<u>Unit Cost, \$/kg HM</u>
Levelized capital charge	6.10
Levelized operating charge	<u>2.80</u>
Levelized total unit cost	8.90 $\pm 30\%$

The above cost estimates are derived for 12-in. dia canisters. Allowable heat limits at the repository may dictate the use of canisters as small as 6-in. in dia. To determine the cost relationships for smaller diameter canisters, the major equipment needs and cycle times were reviewed for operations with a 6-in. canister. From this review, the capital and operating costs were revised and a new unit cost factor derived which, when multiplied by the cost for 12-in. canisters, would give the estimated cost if 6-in. canisters were used. The unit costs were assumed to vary inversely as the square of the diameters according to the following relationship:

$$\frac{C_{x\text{-in.}}}{C_{12\text{-in.}}} = \left(\frac{D_{12\text{-in.}}^2}{D_{x\text{-in.}}^2} \right)^k \quad (1)$$

where $C_{x\text{-in.}}$ = unit cost of x-in. dia canisters
 $C_{12\text{-in.}}$ = unit cost of 12-in. dia canisters
 $D_{x\text{-in.}}$ = dia of x-in. canister
 $D_{12\text{-in.}}$ = dia of 12 in. canister
 k = constant exponent

Using the previously estimated unit cost factor for 6- and 12-in. dia canisters, the above relationship was solved for the exponent k which was found to be 0.6. The unit cost factors for 8- and 10-in. dia canisters were then derived. The cost factors corresponding to the different diameters are 10 in. = 1.25; 8 in. = 1.64 and 6 in. = 2.33.

4.1.1.11 Waste Vittrification Facility Construction Requirements

Many factors relating to site preparation and construction of the WVF may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating the impact of WVF construction activities.

Project Schedules and Construction Manpower. The schedule for engineering, procurement, and construction of the WVF is an integral factor in the overall schedule for the FRP. The field labor force estimated for the construction of the WVF is tabulated below:

	Man-hours, 1000s
Manual field labor	1080
Nonmanual field labor	<u>240</u>
Total field labor	1320

Distribution Between Onsite and Offsite Costs. Onsite costs are those for all construction, materials and services provided at the site of the FRP while offsite costs are those for all services provided, equipment fabricated and/or assembled, and material purchased off of the site of the FRP. The distribution of total costs in these categories is as shown below:

	Costs, \$1000s
Onsite	17,000
Offsite	<u>30,000</u>
Total	47,000

Site Requirements. The reference WVF is contiguous with the FRP and thus shares the overall siting requirements of the FRP. The WVF takes up an area 26 m (85 ft) x 26 m (85 ft) at the FRP site. Installation of the WVF also requires a water storage facility for interim storage of the filled waste canisters and a canister shipping facility for off-site shipment of the canisters. These two facilities, which require about 10 times the space of the WVF, are described in Section 5.4.

Water. About $17,000 \text{ m}^3$ (4.5×10^6 gal) of water is required during construction.

Construction Materials. Materials committed to construction are:

Concrete	6100 m^3	(8000 yd^3)
Steel*	1680 MT	(1850 tons)
Copper**	18 MT	(20 tons)
Zinc	0.9 MT	(1 ton)
Lumber	330 m^3	(140 MFBM)

Energy. Energy resources used during construction are:

Propane	150 m^3	(40,000 gal)
Diesel fuel	$1,510 \text{ m}^3$	(400,000 gal)
Gasoline	980 m^3	(260,000 gal)
Electricity		
Peak demand	400 kW	
Total consumption	750,000 kWh	

Transportation Requirements. No transportation requirements separate from those of the FRP have been identified for the WVF.

4.1.1.12 Effects of Fuel Cycle Options

The reference process for HLW vitrification assumes reprocessing of LWR fuel and recycling the retrieved uranium and plutonium. The following alternative fuel cycle modes have also been assessed insofar as they relate to HLLW vitrification.

No Recycle. With no fuel reprocessing, the highly radioactive fission products contained in spent fuel are not separated out as high-level liquid wastes. Accordingly HLLW vitrification facilities are not required.

Uranium Recycle Only, with Plutonium Stored Separately. This alternative is expected to generate about the same amount of concentrated HLLW as in the uranium and plutonium recycle case. The heat generated by the waste, however, would be lower because fewer heat-generating actinides would be present (see Table 4.1.2). No significant change in the WVF would be necessary.

Uranium Recycle Only, with Plutonium to HLW. This alternative would also generate about the same amount of concentrated HLLW as in the uranium and plutonium recycle case. Because of criticality problems during liquid tank storage the plutonium waste stream would not be combined with the HLLW. Instead, the liquid $\text{Pu}(\text{NO}_3)_4$ waste would be metered separately into the vitrification process from a critically-safe feed tank. The volume of resulting glass would be increased by about 10%. If desired, this volume increase could be accommodated without increasing the number of waste canisters since they are nominally filled to only 80% capacity. The long-term heat content of the canisters would also be increased. After 100 years canisters containing plutonium would generate about twice as much heat as the reference canisters, which

* Includes structural equipment, piping, conduit, rebar, etc.

**Primarily wire and cable

contain no plutonium. (See Table 4.1.2). Considerable research and development would be required for implementing this fuel cycle mode. With about 29.1 kg of PuO_2 added to each canister of HLW glass via this option, criticality questions would have to be resolved. A criticality safety analysis has been conducted for the spray calciner/in-can melter, its associated equipment, and its waste glass product, in terms of the effect of this increase in plutonium content. The analysis indicates that there should be no insurmountable criticality safety problems associated with the vitrification system. Criticality problems may exist in the handling of the filled canisters, however.

The criticality safety analysis of the calciner-melter system is based on a number of assumptions. To avoid criticality problems in the high-level liquid waste feed tank (capacity 5.7 m^3) it is assumed that the purified $\text{Pu}(\text{NO}_3)_4$ from the FRP is held in its own geometrically-safe feed tank (capacity $.35 \text{ m}^3$) and metered directly to the feed atomizing nozzle on the spray calciner. The plutonium is then assumed to be completely calcined in a uniform mixture with the other waste. The calcine product is assumed to have a bulk density of 1.2 g/cm^3 , corresponding to a specific volume of 51.7 l/MTHM . Uniform melting of the calcine and frit would produce a waste glass having a density of 3.0 g/cm^3 and a specific volume of 64.1 l/MTHM . A large amount (10 kg/MTHM) of natural gadolinium, a thermal neutron poison added during spent fuel dissolution, is assumed to be present in both the waste feed solution and the dry waste products.

Even with completely uniform mixing, the k_{∞} for calcine is 1.313; i.e., a large enough accumulation of the calcine could become critical. This is not a factor in the spray calciner/in-can melting process, however, since the process is designed to have no calcine holdup. The calcine is converted to glass immediately after its formation.

Criticality safety control in the resulting waste glass product depends on whether or not the plutonium oxide tends to concentrate due to precipitation and settling during the melting process. Calculations show that because of the high boron and gadolinium content in the glass, a homogeneous distribution will result in a k_{∞} less than unity at the proposed uniform density of $0.15 \text{ g PuO}_2/\text{cm}^3$. Specifically, k_{∞} would be about 0.34, which means that the system is subcritical regardless of amount or geometry.

If, however, the plutonium oxide settles to a higher concentration, k_{∞} may exceed unity, and further analysis considering total fissile mass and geometry may be needed. Preliminary tests with some waste glass compositions indicate the PuO_2 solubility limit is in the range of 1.5-2.0 wt%. Thus, with the fuel cycle option under discussion here, over half the plutonium present could be insoluble. It is probable that much of the insoluble PuO_2 would remain suspended in the glass until it had cooled and become so viscous that no more settling could occur. But, experimentation is required to determine the actual amount of settling and prevention methods.

The effects of maximum settling have been analyzed. As shown in Figure 4.1.12, the value of k_{∞} is >1 when the density of PuO_2 in the glass exceeds about 0.6 g/cm^3 . Thus, further investigation is necessary to determine if it is possible for the density of PuO_2 to exceed

* k_{∞} = criticality factor for an infinite system

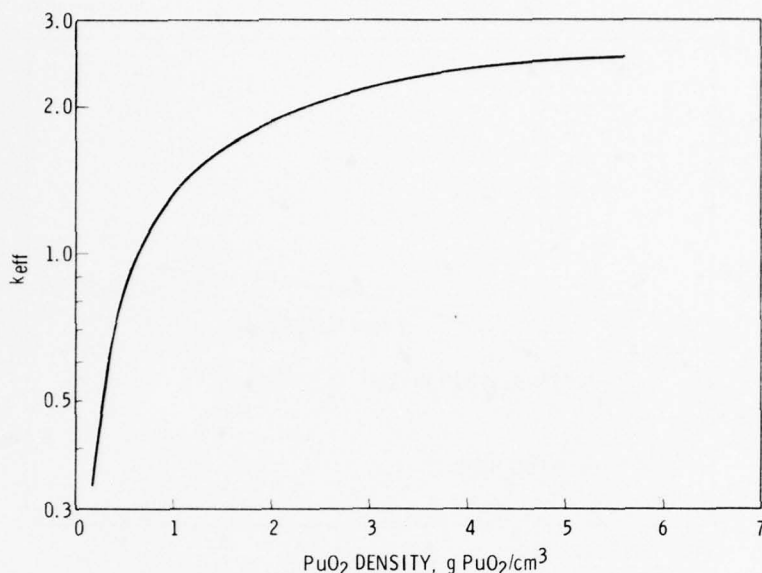


FIGURE 4.1.12. Effect of PuO₂ Concentration on k_{∞} of Borosilicate Waste Glass

this value. To get an indication of the magnitude of this problem, a set of simplified calculations of k_{eff}^* was made using finite values of glass mass and canister dimensions based on design conditions. The entire mass of 29.1 kg of plutonium was assumed to settle into a uniform glassy plug of various densities (and corresponding heights) in a 12" schedule 40 pipe with full graphite reflection. Graphite was chosen because it gives a higher system k_{eff} than any other reflector expected to be encountered. The results are shown in Figure 4.1.13. For a PuO₂ density > 3.5 g/cm³, k_{eff} is > 0.9, which would begin to indicate a criticality potential, requiring perhaps a reduction in the mass of the glass or in canister dimensions. For a PuO₂ density in the range of 1.0 to 3.5 g/cm³, such reductions might still be needed since the simplified model used in these calculations may not represent the most reactive condition. It is clear that this criticality question cannot be fully resolved until experimental information on the solubility of PuO₂ in waste glass and on the maximum concentrations of precipitated PuO₂ become available. These additional considerations will also affect the criticality safety analysis of all subsequent operations involving canisters of glass waste with discarded plutonium, including handling, transportation, interim storage, and final isolation.

4.1.2 High-Level Waste Calcination

Calcination as an alternative form of HLLW treatment will be discussed here so that the relative merits of vitrification versus calcination may be evaluated. Calcination of high-level liquid waste is a primary step in the vitrification process. With sufficient high temperature treatment to remove potential sources of volatiles, the calcined waste meets the present Federal regulations for solidified HLW without the additional complications of conversion to glass.

* k_{eff} = effective criticality factor

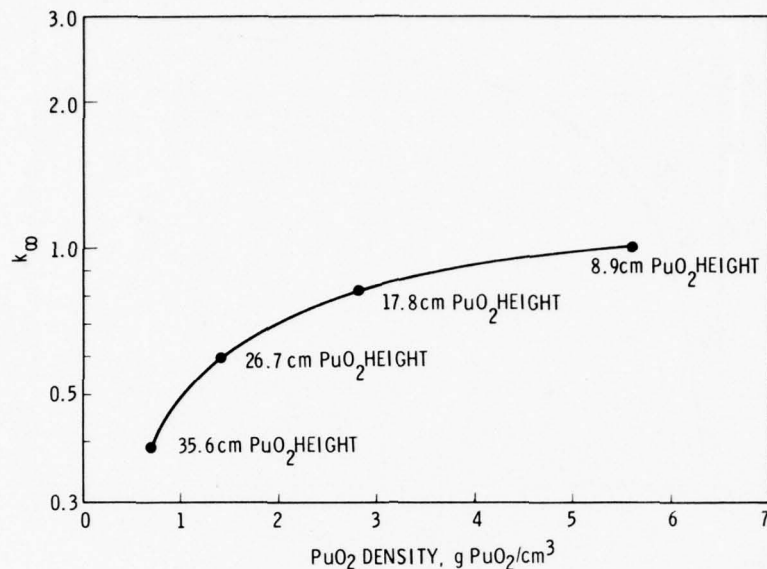


FIGURE 4.1.13. Effect of PuO₂ Concentration on k_{eff} of Borosilicate Waste Glass Contained in a Fully Graphite-reflected Canister 30 cm in diameter

4.1.2.1 High-Level Waste Calcination Process Alternatives

A fluidized bed calcination process has been operated by at the Idaho National Engineering Laboratory (INEL) since 1963 for conversion of DOE radioactive waste solution to granular solids. The INEL process differs from light water reactor (LWR) HLLW solidification facilities in two important ways:

- The waste solutions have a different chemical composition and are about 500 times less radioactive.
- The calcine is stored in vented bins onsite, i.e., it is not sealed in canisters for transport offsite.

Extensive operating experience with fluidized bed calcination at INEL has demonstrated the reliability of this processing concept.⁽⁸⁾ Development studies at INEL and PNL have shown also that HLLW from an LWR can be solidified by fluidized bed calcination, with suitable process modifications.⁽⁹⁾

Other calciners have been specifically developed for commercial HLLW calcination, including pot calciners, spray calciners and rotary kilns. These calciners were reviewed in a previous report⁽²⁾ and fluidized bed calcination was identified as being the most well-developed calcination process. It has, therefore, been selected as the reference calcination process for this report.

4.1.2.2 Waste Calcination Facility Design Basis

The design basis assumed for the waste calcination facility (WFC) includes the following:

- Process HLLW from 2000 MTHM/yr
- .6 m³ (150 gal) HLLW/MTHM
- 300 days facility operation/yr
- peak design capacity = 1.5 nominal design capacity = 5.7 m³ (1500 gal)/day

The reference waste calcination facility is designed to be close-coupled to the FRP; there will be no interim storage of the HLLW before calcination. The spent fuel will be cooled 1.5 years before reprocessing. The thermal power generation rate of 1.5 year old HLLW was given earlier in Table 4.1.2.

4.1.2.3 Waste Calcination Facility Process

The WCF produces a thermally-stabilized calcine powder in canisters 20 cm (8 in.) in dia x 305 cm (10 ft) long for storage and ultimate disposal. A smaller diameter canister is used for waste calcine than for waste glass to prevent overheating at the centerline of the canister, since the thermal conductivity of calcine is approximately 25% that of glass. Figure 4.1.14 is a flow diagram of the reference WCF process. The calcination process reduces about 20 volumes of liquid to one volume of solid. The process may be divided into four components: 1) calcination and canister filling, 2) calcine stabilization, 3) off-gas treatment, and 4) canister sealing and decontamination. The distribution of radioactivity in the feed to the process is the same as for the WVF given in Table 4.1.3. Table 4.1.17 describes the product from the calcination process.

Calcination and Canister Filling. Two waste hold tanks are used to maintain a continuous supply of HLLW from the FRP to the calciner. One tank is filled while the other tank is emptied to the calciner. The HLLW is pumped to the calciner through a pneumatic atomizing nozzle. The calciner is heated with an in-bed combustion (IBC) system in which a mixture of kerosene and oxygen is burned in the bed of the calciner to maintain the temperature at 500°C. When the atomized HLLW is injected into the hot bed, the waste constituents are converted to solids (primarily oxides), which adhere to the surface of particles already in the bed. The bed is in dynamic equilibrium; new particles are nucleated on small pieces spalled off larger particles, so that the bed particle inventory remains constant even though product calcine is continuously removed. The bed is fluidized by heated air entering through perforations in the support plate.

The product calcine is collected in two streams. One consists of powder taken from a bed overflow line; the other consists of fines removed from the off-gas stream via a cyclone. In both cases, gravity is used to transfer the solids to an interim storage vessel for temporary holdup until canisters are ready for filling. The hold vessel is water-cooled to dissipate the heat generated by the calcined waste. A similar calcine hold vessel is maintained as an empty spare in the event fluidization in the calciner is lost and an emergency dump of the bed is required.

The canisters are filled with calcine by gravity flow from a slide valve at the bottom of the calcine hold vessel. During normal operation a canister is filled every 10.5 hr. The canisters are filled to approximately 80% full capacity.

Calcine Stabilization. Federal regulations require that the solidified waste be chemically, thermally, and radiolytically stable so that pressurization of the sealed canisters does not occur. Calcine formed at the 500°C operating temperature of the WCF requires further treatment to remove residual water and nitrate in order to meet this requirement.

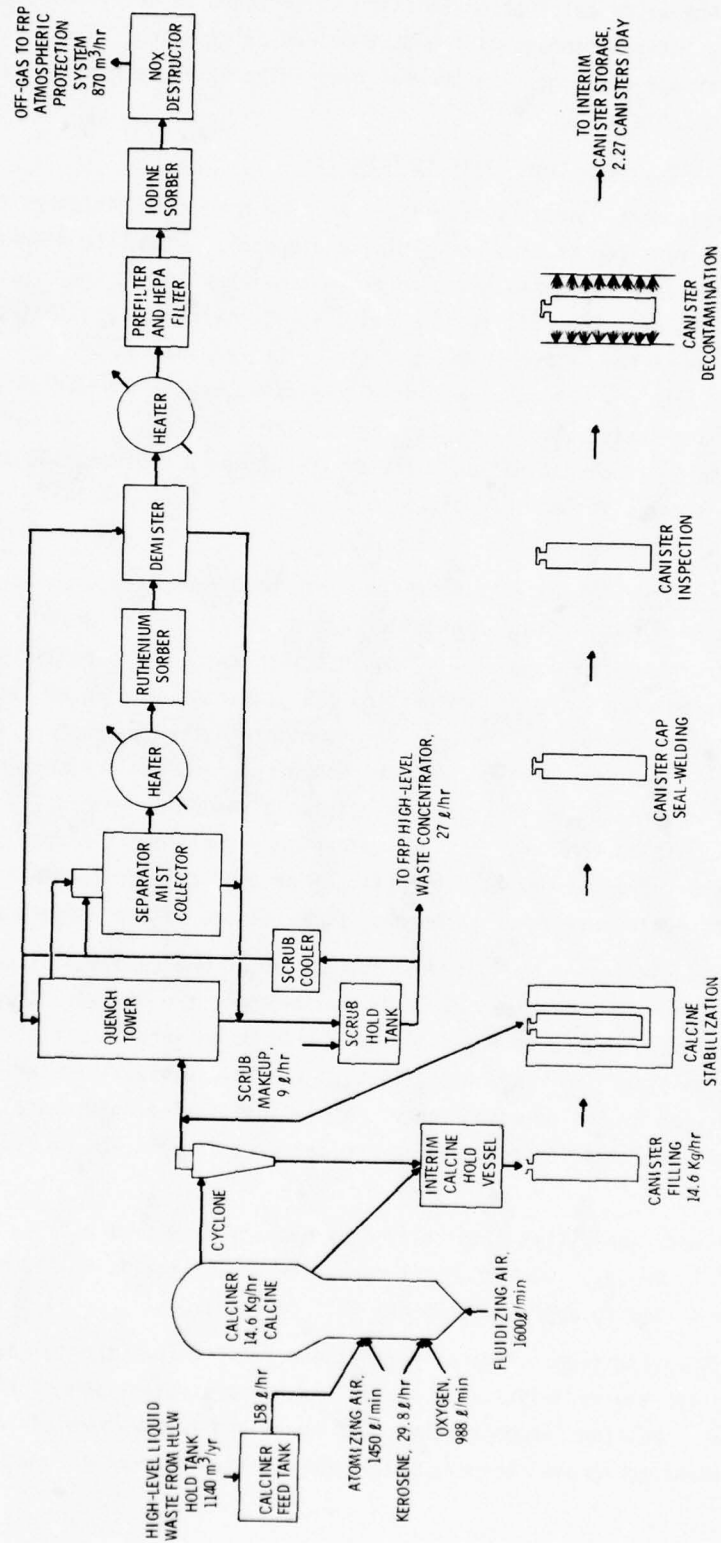


FIGURE 4.1.14. HLLW Calcination Process Flowsheet

TABLE 4.1.17. Description of Solidified Waste from Waste Calcination Facility

Volume of calcine	48 m ³ /yr
Density of calcine	2200 kg/m ³
$\frac{\text{Treated volume}^{(a)}}{\text{Untreated volume}}$	0.052
Canisters ^(b) /yr	683
Leach rate of calcine in water @ 25°C	20-25% of the most soluble constituents, such as Cs and Sr dissolve in <1 week
Radioactivity in calcine, fraction of input(c):	
³ H	0
¹²⁹ I	0
All other fission products and actinides	1.0

a. Treated volume based on canister volume with canisters 80% filled.

b. 20 cm dia x 3 m long.

c. See Table 4.1.3.

The residual water and nitrate are removed by heating each canister to 700°C while the contents are fluidized with air. Each canister is fitted with a fluidizing gas line leading to a sintered metal support plate at the bottom. Two hours at temperature are sufficient to remove the residual water and nitrate.⁽¹⁰⁾ Remotely attached connections vent the calcine stabilization off-gas to the calciner off-gas cleanup system.

Off-gas Treatment. The WCF process off-gas comprises all process air streams, vaporized water, nitric acid, decomposed nitrates, and fine particles. This off-gas passes through a cyclone, where most of the solids are removed. The design objective of the cyclone is to collect as many of the solids as feasible in order to minimize the quantity of solids collected in the scrub system. The cyclone should collect at least 50% of all particles larger than 2 µm in diameter. The collected particles are transferred by gravity to the calcine hold vessel.

After leaving the cyclone, the off-gas is cooled in a quench tower and scrubbed in a venturi scrubber with recirculating 1.5M HNO₃. The off-gas then passes through a silica gel bed for ruthenium adsorption, a prefilter/HEPA filter combination for further particle removal, a silver zeolite adsorber for iodine removal, and a NO_x destructor. The NO_x destructor utilizes the exothermic reaction of NO_x and NH₃ on a zeolite catalyst, which converts the two gases into nitrogen and water vapor. Gas heaters and coolers are provided as needed in the off-gas system. The treated process off-gas from the WCF is routed to the FRP atmospheric protection system for dilution and a final filtration treatment before release to the atmosphere.

Canister Sealing and Decontamination. After the calcine stabilization step is completed the off-gas connector is uncoupled and the canister is moved to the welding station where a cap is seal-welded on the canister. Such quality assurance tests as may be required are conducted at this time. The canister is then moved to the canister decontamination cubicle where surface contamination is removed by a high pressure water spray treatment prior to transfer to the water basin storage.

Optional Processing Modes. In the reference calcination process only HLLW is fed to the fluidized bed calciner. It is, however, possible to calcine other wastes with the HLLW with very little impact on the process. Two such optional combinations are described below.

Combining ILLW with HLLW. Reprocessing plants have the option of combining their intermediate-level liquid waste with HLLW prior to solidification. As described in Section 4.1.1.3, the major impact of adding ILLW to HLLW in the reference facility is to increase the volume of calcine by 34%. Since the heat produced by ILLW is insignificant compared to HLLW, it would be possible to increase the calcine canister diameter to 25 cm and accommodate the added volume of ILLW without increasing the canister throughput rate in the WCF.

Disposal of Spent Solvent in the Waste Calcination Facility. Spent solvent can be burned in the WCF with little modification to the equipment, since spent solvent is 70 vol% organic diluent of a composition very similar to the kerosene fuel used for in-bed combustion. The spent solvent can be introduced through the fuel nozzle. The tributyl phosphate component of the spent solvent will decompose, forming harmless CO_2 and H_2O in the off-gas and inorganic phosphates that become part of the calcine. The volume increase of the calcine is negligible.

4.1.2.4 Waste Calcination Facility Description

The WCF is assumed to have been constructed as an integral part of the reference FRP. The location of the WCF in the FRP is the same as that of the WVF (see Figure 4.1.2). The overall facility dimensions, cell dimensions and equipment layout for the WCF are shown in Figures 4.1.15 through 4.1.20.

Waste Calcination Cell. The waste calcination cell (WCC) for the WCF is located in the remote process cell area of the FRP process building. The service and support facilities for this cell are integrated with the FRP. The WCC contains the equipment directly associated with waste calcination and canister postfill operations up to decontamination of the sealed and inspected canisters.

Off-Gas Cell. The off-gas cell houses the iodine adsorber and the NO_x destructor. Background activity levels in this cell are about 100,000 times lower than in the WCC. The off-gas filters are housed in a special filter niche between the WCC and the off-gas cell for ease of replacement.

Cell Lining. The WCC and canister decontamination cell (CDC) are fully lined with stainless steel. The hot maintenance area, the hot pipe trench and the filter and iodine sorber niches are also lined with stainless steel. The off-gas cell has a stainless steel floor pan, with the walls and ceilings covered with a radiation resistant coating.

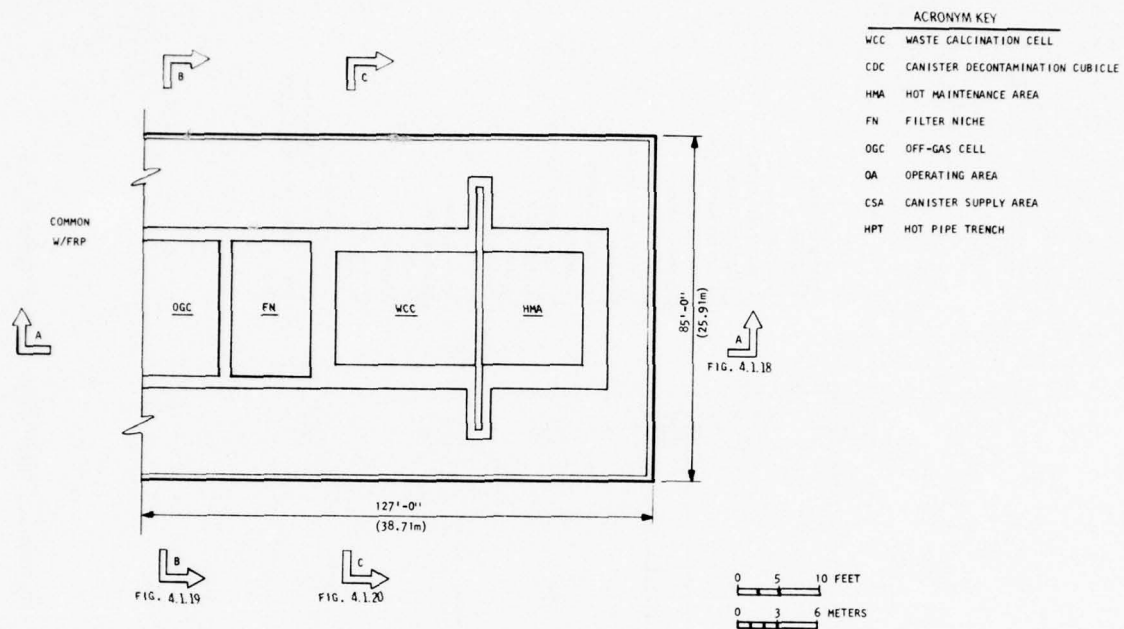


FIGURE 4.1.15. Waste Calcination Process Key Plan

Major Equipment. The fluidized bed calciner, calcine hold vessel and calcine canister are among the equipment specially designed for the WCF. Other major items with less unique design features include the calcine posttreatment furnace, the welding and inspection station, the liquid feed system, and the components of the off-gas system.

Fluidized Bed Calciner. The fluidized bed calciner is shown in Figure 4.1.21. It has an overall height of 2.7 m. The calciner, consisting of a bed chamber with a diameter of 0.7 m and a height of 0.9 m, is located below a deentrainment section that has a diameter of 1.2 m and a height of 1.6 m. The bed chamber is operated at 500°C by burning a mixture of kerosene and oxygen within the bed. The nozzle for kerosene-oxygen is located below the feed nozzle through which the HLLW is atomized with air into the bed. Calcine is withdrawn continuously from the bed via the product takeoff line. The calcine is collected in the calcine hold vessel.

Redundant fluidizing air inlets and calcine drain lines, not shown in Figure 4.1.21, are provided. The emergency fluidizing air inlet is connected to an independent air supply. Emergency calcine removal can be effected by dumping the calcine through a drain line in the distributor plate or by vacuum withdrawal through another line above the distributor plate. The emergency calcine removal lines lead to the bed dump hopper, a water-cooled storage vessel of identical design to the calcine hold vessel.

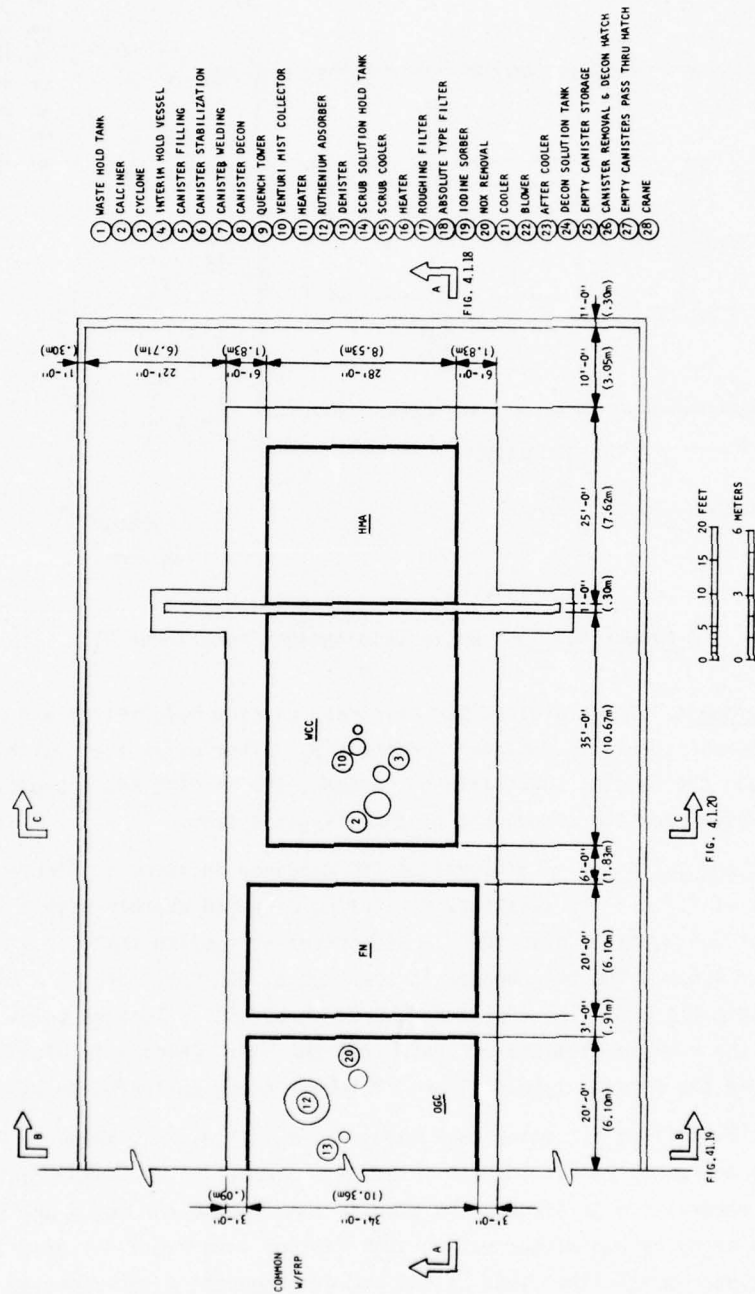


FIGURE 4.1.16. Waste Calcination Process Equipment Arrangement, Upper Plan (See Figure 4.1.5 for acronym key.)

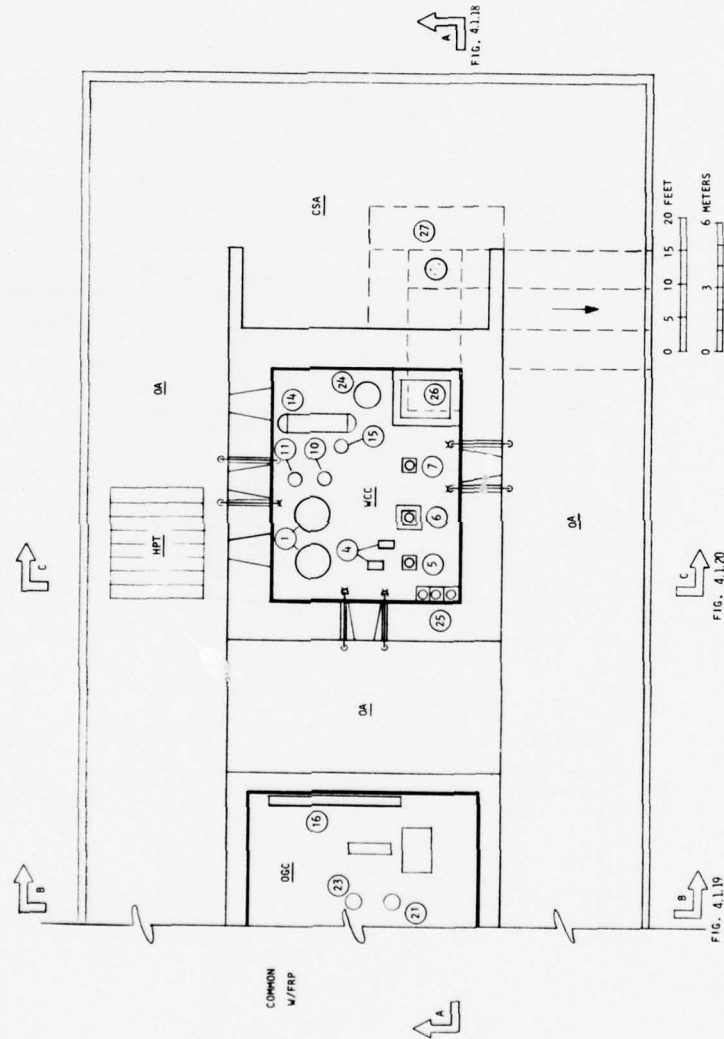


FIGURE 4.1.17. Waste Calcination Process Equipment Arrangement, Lower Plan
(See Figure 4.1.15 for acronym key and Figure 4.1.16 for key to circled numbers.)

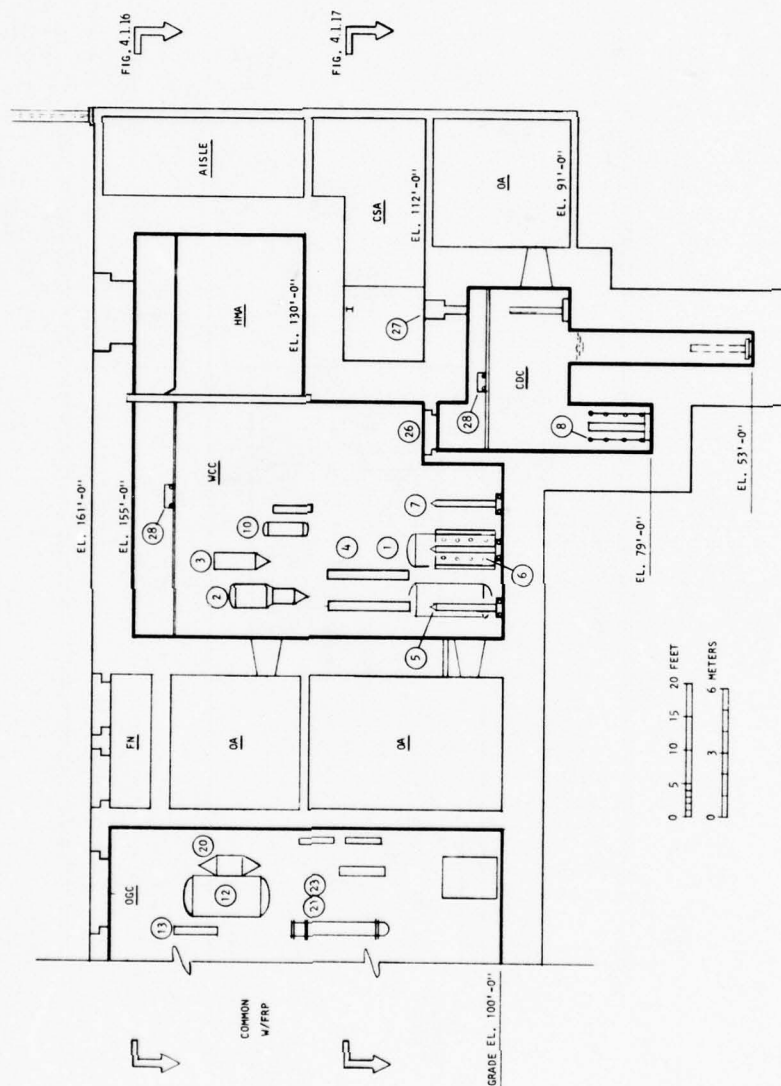


FIGURE 4.1.18. Waste Calculation Process Equipment Arrangement, Section A-A. (See Figure 4.1.15 for acronym key and Figure 4.1.16 for key to circled numbers.)

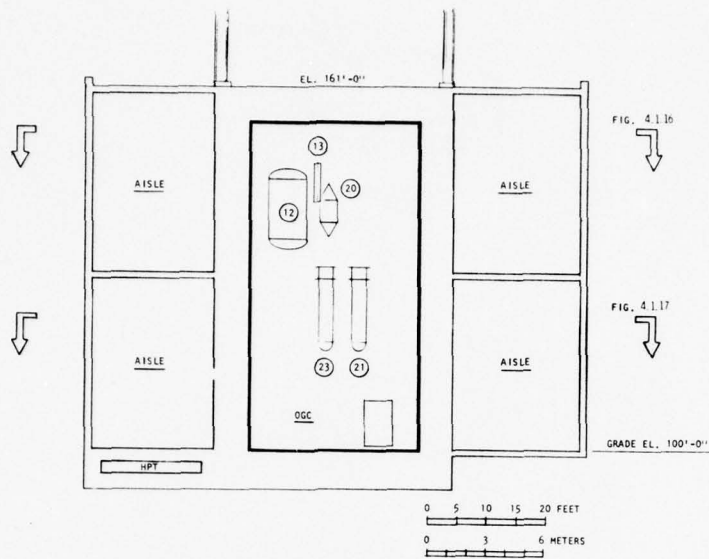


FIGURE 4.1.19. Waste Calcination Process Equipment Arrangement, Section B-B
(See Figure 4.1.15 for acronym key and Figure 4.1.16 for key to circled numbers.)

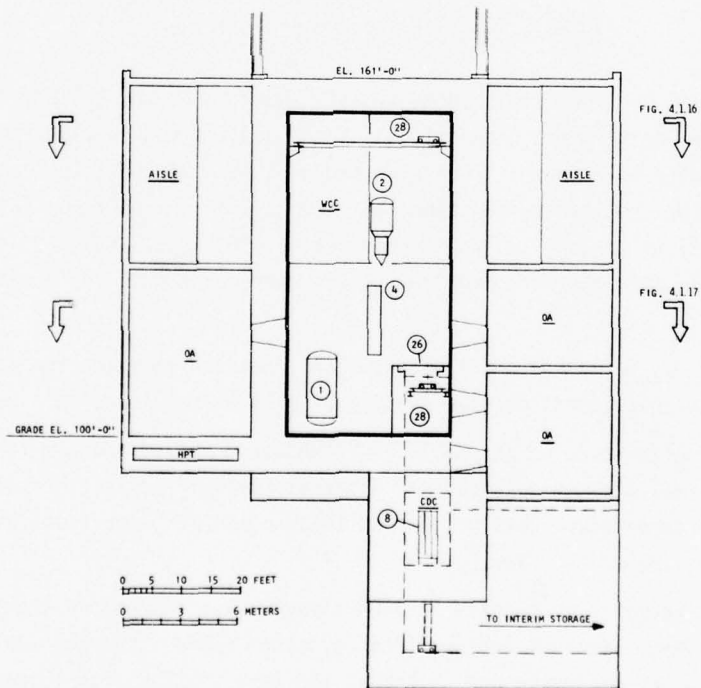


FIGURE 4.1.20. Waste Calcination Process Equipment Arrangement, Section C-C
(See Figure 4.1.15 for acronym key and Figure 4.1.16 for key to circled numbers.)

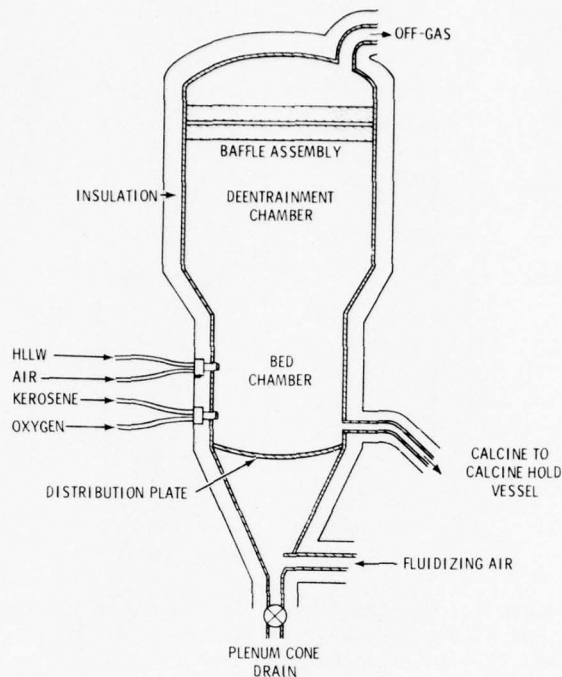


FIGURE 4.1.21. Fluidized Bed Calciner

Calcine Hold Vessel. The calcine hold vessel, shown in Figure 4.1.22, serves as a surge tank to store calcine between its generation in the fluidized bed calciner and its loading into canisters. The calcine hold vessel is constructed of 304L stainless steel and has a capacity of 310 ℓ of calcine. The calcine is maintained at a centerline temperature less than 700°C by cooling water that flows through the cooling jacket at 1.8 ℓ /min. Calcine is transferred by gravity through a remotely-operated coupling to canisters on a dolly underneath the calcine hold vessel.

HLW Calcine Canisters. Figure 4.1.23 shows the canister in which the calcine is stored. The design is conceptual; actual calcine canisters could differ in certain details.

The canister, which is 20 cm in dia (8-in. Schedule 40 pipe) and 3 m long, is constructed of 304L stainless steel. Eight longitudinal internal cooling fins are provided to assure that the centerline temperature does not exceed the processing temperature of the calcine at any time during handling or storage.

The canisters are moved on a dolly through a sequence of operating stations in the waste calcination cell. These stations include loading, posttreatment furnace and the welding and inspection station. The canisters are fitted at the last station with a standardized remote grapple fitting, shown in the cap detail in Figure 4.1.23, to facilitate handling in the subsequent stages of management of the HLW canisters.

4.1.41

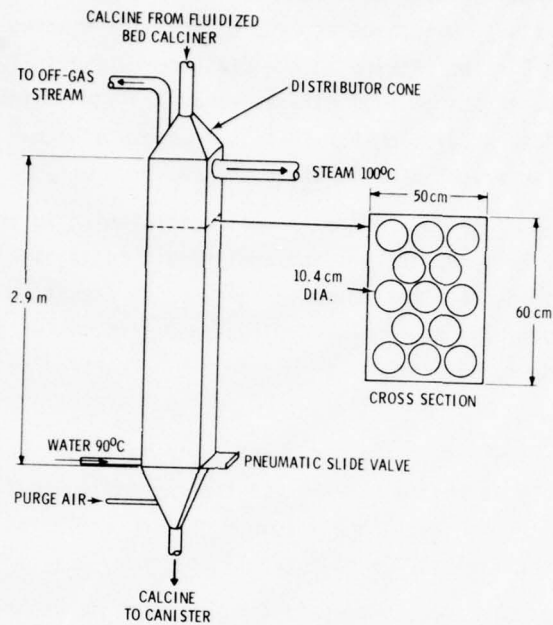


FIGURE 4.1.22. Calcine Hold Vessel

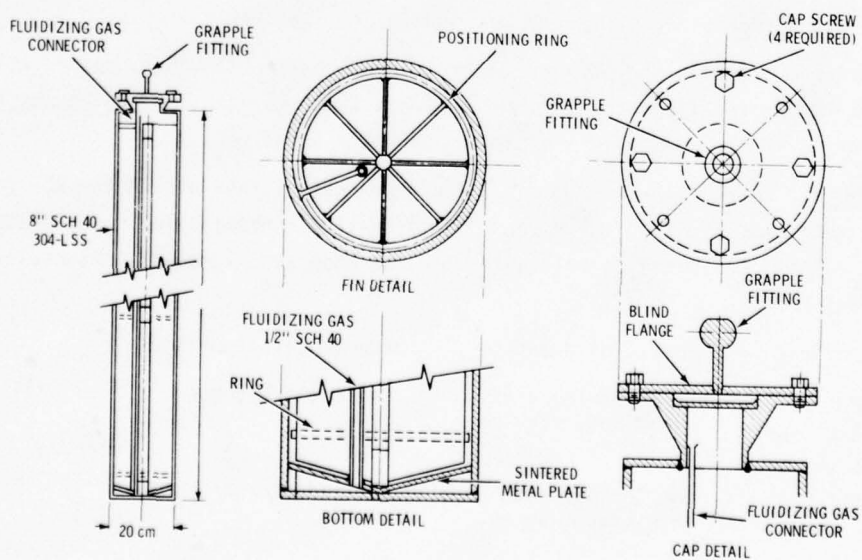


FIGURE 4.1.23. Canister for Calcined HLW

Posttreatment Furnace. The posttreatment furnace, a 120-kW radiant heat furnace of clam-shell construction, is clamped around each canister in turn as it passes through the station. Maximum design temperature of the furnace is 1100°C for quick heating of all calcine in the canisters to at least 700°C. The calcine in the canister is partially fluidized during the thermal treatment to increase the rate of off-gas removal. The fluidizing gas inlet and off-gas vents are built into a pivoting arm that is remotely attached to each canister before heat is applied. The off-gas vent line leads to the calciner off-gas system.

Welding and Inspection Station. After thermal conditioning in the posttreatment furnace each canister is moved by dolly to the welding and inspection station. Here the canisters are seal welded using a tungsten-inert gas welder. The welding operation is automated; the welding station is located in front of a viewing window equipped with master-slave manipulators so that hand-controlled repairs or modifications can be made if a check of the weld quality indicates the need.

Liquid Feed System. Two 304L stainless steel waste feed tanks are provided to maintain a continuous supply of HLLW to the calciner. One tank is filled on a batch basis while the other tank is metered to the fluidized bed calciner. Each tank holds 4 m³ HLLW at 60°C. The heat removal/addition capability of each tank is 15 kW.

Off-Gas System Components. The process off-gas system components were shown earlier in Figure 4.1.14. The first component is a cyclone 76 cm in dia x 3 m high. It is designed to remove about 6 kg of solids per hour from the off-gas stream. The collected particles are transferred by gravity to the calcine hold vessel. A quench tower and demisters collect most of the remaining particles in a scrub solution that is recycled to the FRP waste concentrators. Prefilters and HEPA filters complete the particle removal from the process off-gas.

Special sorbers are provided for the two potential volatiles in the off-gas, ruthenium and iodine. The sorbants are silica gel and silver zeolite, respectively.

The final component in the off-gas system is a NO_x destructor that uses a zeolite catalyst. An exothermic reaction occurs on the catalyst when ammonia is added to the NO_x; this reaction converts the two gases into nitrogen and water vapor.

Operating Personnel Exposure Control. Zones are established within the WCF for controlling personnel exposure and limiting the spread of radioactive contamination. The presence or possible presence of any contamination will determine the zone and degree of personnel access. The zones are:

Zone 1	Operating areas	Free access (monitored)
Zone 2	Cell service areas (sampling, service galleries)	Controlled access
Zone 3	"Hot" equipment maintenance areas	Limited access
Zone 4	Processing cells	No access

Shielding and Remote Handling Equipment. The WCF is designed to provide adequate shielding for safe operation. In-cell maintenance requires the combined use of a bridge-mounted crane, bridge-mounted electromechanical manipulator, and wall-mounted master slave manipulators. Personnel operating such equipment are shielded by concrete walls 1.8 m (6 ft) thick. Vessel and piping design consider special requirements such as vessel positioning, piping connections, and equipment movement within the cell as they relate to remote operations. Specific items requiring remote replacement capability include: feed and fuel nozzles, scrub and feed control valves, scrub pump, and the feed pump. While much of the movement of canisters in the cell is automated on a track system, connecting and disconnecting canisters into the various portions of the solidification and stabilization process require remote capability, i.e., positioning clamps or attaching piping to the canister.

4.1.2.5 Waste Calcination Facility Operating and Maintenance Requirements

The WCF operates 24 hours a day, 7 days a week. There are certain requirements for start-up and shutdown of the fluidized-bed calciner. For initial startup, a bed must be placed in the calciner. Dolomite (Ca,MgCO_3) is used for this initial bed. The bed is then fluidized with heated air until the bed temperature reaches the auto-ignition temperature of oxygen-kerosene (365°C), at which time the oxygen and kerosene streams are turned on and in-bed combustion heating begins. Nitric acid is fed through the waste feed nozzle to aid in the initial startup of oxygen-kerosene combustion. As soon as in-bed combustion heating is established and the bed temperature reaches 500°C , feeding of HLLW begins.

During short shutdowns of the calciner, the bed will be maintained in a fluidized condition with fluidizing air. This will prevent overheating in the calciner which could cause concretion of the bed. For prolonged shutdowns of the fluidized bed calciner (shutdowns exceeding a few days) the bed will be discharged to the bed dump hopper. Restart will follow the procedure described above.

During routine operation the calciner is in continuous, steady-state operation. Most of the WCF operating requirements center around the canisters, one of which is filled every 10.5 hours. A combination of automated and remote handling steps is needed for canister movement within the cell. Once empty canisters are brought into the process cell through an air lock, they are installed below the solids storage hopper for filling. Filled canisters are then transported to a stabilization station where remotely-attached connections allow venting of off-gas to the off-gas cleanup system. Once stabilization is completed, the canister moves to an automated welding station for sealing. Canister decontamination completes the in-cell operations.

There are no unusual maintenance requirements beyond those characteristic of fully remote, high radiation operations. Waste calcination equipment located in-cell requires a remote maintenance capability for removal and installation of major equipment items and replacement of high frequency maintenance items. Air locks facilitate equipment and tool transfers to and from the process cell.

Staffing Requirements. Table 4.1.18 gives the WCF staffing requirements.

TABLE 4.1.18. Waste Calcination Facility Staffing Requirements

<u>Job Description</u>	<u>Personnel Required, man-yr/yr</u>
Operators	19
Radiation monitors	1
Maintenance craftsmen	9

Supplies and Utilities. Table 4.1.19 shows the annual usage of supplies essential to the WCF process. A summary of the utility requirements is given in Table 4.1.20. The utility requirements are of the same type as the FRP and thus represent incremental additions to the utility capacity already provided for that plant.

TABLE 4.1.19. Waste Calcination Facility Supply Requirements

<u>Supply</u>	<u>Use</u>	<u>Annual Requirement</u>
Kerosene	In-bed combustion	215 m ³
Oxygen	In-bed combustion	430,000 m ³ (STP)
Ammonia	NO _x destruction	210,000 m ³ (STP)
Nitric acid (12.2 M)	Scrubber makeup solution and decontamination	60,000 kg
Detergent	Decontamination and cleaning	100 kg
Silver zeolite	Iodine adsorber	64 kg

TABLE 4.1.20. Waste Calcination Facility Utility Requirements

<u>Utility</u>	<u>Use Rate</u>	<u>Annual Requirements</u>
Electricity	755 kW	5 x 10 ⁶ kWh
Water consumed	9.7 m ³ /day	2900 m ³
Steam	80 kg/hr	5.8 x 10 ⁵ kg

Compressed Air Systems. Clean, dry, oil-free air at 7.0 atm is used for process, instrument, and utility needs. Air distributed throughout the facility @ 6.8 atm is used for air sparging, pneumatic solids transport, and supply for lower pressure service systems. Pressure reducing stations supply 1.3 and 3.4 atm air for waste atomization, air lifts, instrumentation and purge application. Compressed air introduced into process vessels and piping becomes part of the calciner off-gas and is subject to extensive cleanup in the off-gas system. Any air utilization external to the process but inside the process cells is added to the cell ventilation air, which is filtered prior to release to the environment.

Steam System. Steam required for ejectors, process heating, pipe tracing, equipment decontamination, and various utility systems is supplied from an existing onsite steam generator. A nominal supply pressure of 10 atm is reduced to 2 atm as needed within the facility. Steam production will generate 12 kg of steam for each liter of #6 fuel oil consumed.

Calciner Fuel System. A bulk oxygen supply is needed for the in-bed combustion system since adequate combustion of the fuel for the operating conditions can only be attained through the use of a pure oxygen stream. A vendor-supplied cryogenic storage system capable of providing 0.85 scmm of oxygen @ 8.2 atm is adequate. Sizing of the liquid oxygen storage vessel is dictated by site requirements and availability of supply from the geographic area.

A hydrocarbon fuel, usually kerosene, is used with the in-bed combustion system. Maximum rate of consumption is 30 l/hr. The fuel storage tanks are located outside the solidification facility at a distance that does not significantly endanger the facility from a fire or explosion of the fuel tank. Fuel is pumped to the WCF through an encased underground line.

4.1.2.6 Waste Calcination Facility Secondary Radioactive Wastes

Secondary radioactive wastes produced by the WCF are shown in Table 4.1.21. Failed equipment and solid trash from the WCF have no unique characteristics that require special treatment and are disposed of via the facilities for these types of wastes in the FRP. The liquid secondary wastes are recycled back to the FRP high-level waste concentrator.

TABLE 4.1.21. Waste Calcination Facility
Secondary Radioactive Wastes

Description	Volume, m ³ /yr	Radioactivity Factor ^(a)
Combustible and compactable waste	91	1×10^{-6}
Failed equipment and noncombustible trash	35	1×10^{-6}

a. Fraction of input activity (Table 4.1.3) in secondary wastes.

4.1.2.7 Waste Calcination Facility Emissions

Air and water constitute WVF emissions ultimately released to the environment. The air from the process equipment and the cell ventilation is radioactive. The properties of those air streams and their activity are shown in Table 4.1.22. Table 4.1.23 lists the decontamination factors (DF) assumed for each of the components of the in-cell off-gas train. The off-gas then passes through the FRP APS where an additional 10^4 DF is obtained for particles.

An estimate of the integrated annual release due to minor accidents (Section 4.1.2.9) for this facility is included in Table 4.1.22. It was developed by weighing the minor accident releases by their expected frequencies and summing the quantities for all identified minor accidents. In addition, a contingency was included in the integrated release to account for unidentified minor accidents and to compensate for the uncertainty in expected frequency information. Estimated integrated annual releases due to minor accidents for this technology is shown in Table 4.1.22.

There are no other significant effluents from the WCF. There are no obnoxious noises, odors, or vibrations associated with operation of the WVP.

TABLE 4.1.22. Waste Calcination Facility Emissions

Emission	Description	Annual Quantity	Radioactivity Release Factor to Atmosphere(a)
Gaseous	Process off-gas, ventilation air, and vaporized excess water	$1.3 \times 10^8 \text{ m}^3$	^3H 1.0
			^{129}I 1×10^{-3}
			Ru 5×10^{-12}
			All others 2×10^{-15}
			All 2×10^{-16}
	Minor accident integrated annual release		
	Ammonia(b)	$4.6 \times 10^4 \text{ kg}$	
Cooling tower water:	• evaporated, $T = 38^\circ\text{C}$	$2.5 \times 10^6 \text{ kg}$	
	• drift, $T = 38^\circ\text{C}$	$1.2 \times 10^4 \text{ kg}$	
	• blowdown, $T = 27^\circ\text{C}$	$4.3 \times 10^5 \text{ kg}$	
Other	Heat	$1.7 \times 10^3 \text{ MW-hr}$	
		$(5.7 \times 10^9 \text{ BTU})$	

a. Fraction of input activity (Table 4.1.3) released to atmosphere. Includes DF from main plant APS where applicable. Released over 300 day/yr.

b. From the NO_x destructor.

TABLE 4.1.23. Estimated Decontamination Factors for Off-Gas Cleanup in Waste Calcination Facility

Equipment	Estimated DF(a)			
	Iodine	Ruthenium	Particles	NO_x
Calciner and cyclone(b)	1	100	100	1
Quench tower, venturi scrubber, and mist eliminator(b)	1	10	10	1
Ruthenium adsorber	1	10^3	2	1
Demister (wet filter)	1	2	2	1
HEPA filter bank	1	10	10^7	
Iodine sorber	10^3	1	1	1
NO_x converter	1	1	1	100
Overall facility DF	10^3	2×10^7	4×10^{10}	100

a. Decontamination factor (DF) = ratio of the activity entering the equipment item to the activity leaving facility.

b. Items treated as a unit.

4.1.47

4.1.2.8 Waste Calcination Facility Decommissioning Considerations

The useful life of the WCF is the same as that of the FRP, 30 years. Residual activity at the time of decommissioning is estimated to be about 1×10^5 Ci after removal of the ruthenium and iodine sorbers. Much of the activity will be associated with fine powdery calcine on the cell walls and floor and will be easily removed during decontamination. After decontamination, the activity remaining in the WCF should be less than 10^3 Ci.

4.1.2.9 Waste Calcination Facility Postulated Accidents

Postulated accidents for the WCF are described in Tables 4.1.24 and 4.1.25. As shown in these tables, redundant safety systems are provided to prevent most types of accidents. In addition, the process operators would be skilled in operating the facility and trained to react quickly to any type of emergency.

TABLE 4.1.24. Waste Calcination Facility Minor Accidents

Accident No. and Description	Sequence of Events	Safety Systems	Release
4.1.11 - Hydrogen explosion in feed tank. Expected frequency $\sim 0.01/\text{yr}$.	<ol style="list-style-type: none"> 1. Extended undetected loss of purge air allows hydrogen accumulation. 2. Ignition source causes hydrogen explosion. 3. Repair or replace equipment as required. 	<ol style="list-style-type: none"> 1. Multiple air purges with flow indicators. 2. Designed to eliminate ignition sources. 	None. Solution safely contained in floor pan.
4.1.12 - HLLW feed system leakage. Expected frequency $\sim 0.1/\text{yr}$.	<ol style="list-style-type: none"> 1. Leakage in pressurized line at fitting or connection. 2. Leakage detected. 3. Leaking equipment repaired. 	<ol style="list-style-type: none"> 1. Primarily welded connections. 2. Sump alarm permits early detection. 	None. Spilled solution safely contained in floor pan.
4.1.13 - Calcine spill during canister filling. Expected frequency $\sim 2/\text{yr}$.	<ol style="list-style-type: none"> 1. Overfilled canister due to operator error or fill control malfunction. 2. Overfill detected. 3. Disconnect canister and remove excess calcine. 	<ol style="list-style-type: none"> 1. System designed to minimize component failures. 2. Canister overload alarm. 	Nominally a few grams of calcine would be released to cell. In the worst case up to 2 kg calcine is released to cell. Seventy percent of this material reaches the cell HEPA's resulting in a 1.5×10^{-5} mg calcine release over 1 hr from the FRP stack.
4.1.14 - Overheating of calciner equipment due to plugging. Expected frequency $\sim 0.01/\text{yr}$.	<ol style="list-style-type: none"> 1. Loss of fluidizing air. 2. Bed removal systems fail. 3. Calcine overheat, and sinters. 4. Cooling provisions improvised and calcine removed. 	<ol style="list-style-type: none"> 1. Redundant fluidizing and bed removal systems. 2. Redundant instrumentation. 	None. Contamination spread during cleanout confined to cell.
4.1.15 - Calcine overheating in canister. Expected frequency $\sim 0.01/\text{yr}$.	<ol style="list-style-type: none"> 1. Faulty furnace control. 2. Loss of canister purge air. 3. Operator error. 4. Canister cooled, inspected and overpacked, if necessary. 	<ol style="list-style-type: none"> 1. Multiple temperature controls and alarms. 	None.

TABLE 4.1.25. Waste Calcination Facility Moderate Accidents

Accident No. and Description	Sequence of Events	Safety Systems	Release
4.1.16 - Feed solution backup in air line or contamination spread to occupied zone. Expected frequency $\sim 0.2/\text{yr}$.	<ol style="list-style-type: none"> 1. Feed nozzle plugs. 2. Atomizing air check valve fails allowing airline to fill with HLLW. 3. Empty and decontaminate the line. 	<ol style="list-style-type: none"> 1. Multiple detection systems. 2. Air supply pressure exceeds feed pressure. 	100 g HLLW backs up in an air line. This presents a line source 1 m long exposing 2 persons 1 m away for up to 10 minutes.
4.1.17 - Calciner pressurization due to malfunction of fuel ignition system. Expected frequency $\sim 0.01/\text{yr}$.	<ol style="list-style-type: none"> 1. Fuel introduced at too low a bed temperature resulting in delayed ignition. 2. Brief pressure surge. 3. Contamination of service connections. 4. Cleanup of service connections. 	<ol style="list-style-type: none"> 1. Interlocks to prevent fuel introduction at low bed temperature. 2. Redundant temperature monitors. 3. Sharp temperature fluctuations prevented by bed heat capacity. 	None. Occupational exposure in cleanup of activity backed up in service connections.
4.1.18 - Failure of off-gas filter or scrubber. Expected frequency $\sim 0.2/\text{yr}$.	<ol style="list-style-type: none"> 1. Filter fails. 2. Failure detected and off-gas diverted to spare filter bank. 3. Filter replaced. 	<ol style="list-style-type: none"> 1. Differential pressure and radiation instrumentation. 2. Spare filter bank. 	1×10^{-3} g of calcine released from the FRP stack over 1/2 hour.
4.1.19 - Off-gas blower failure. Expected frequency $\sim 0.1/\text{yr}$.	<ol style="list-style-type: none"> 1. Mechanical failure or loss of electrical power. 2. Alternate blower or power system activates. 	<ol style="list-style-type: none"> 1. In-line spare blower. 2. Off-gas blowers on emergency power. 	None. Fraction of gram of calcine dust may become airborne, but all contained in cell.
4.1.20 - Off-gas iodine or ruthenium sorber malfunction. Expected frequency $\sim 0.1/\text{yr}$.	<ol style="list-style-type: none"> 1. Exhaustion or degradation of sorbent or bed channeling. 2. Adsorber malfunction detected. 3. Replace adsorbent with fresh adsorbent. 	<ol style="list-style-type: none"> 1. Substantial bed depth used to assure sorptive capacity and minimize channeling. 2. In-line monitoring equipment. 	<100-fold increase in I-129 activity or <10-fold increase in Ru-106 activity in WVF process off-gas to FRP atmospheric protection system, from malfunction of iodine or ruthenium adsorber, respectively.
4.1.21 - Fire in cell. Expected frequency $\sim 0.1/\text{yr}$.	<ol style="list-style-type: none"> 1. Leakage of calciner fuel (kerosene) in cell. 2. Source of ignition causes fire. 3. Fire extinguished. 4. Repair damage as required. 	<ol style="list-style-type: none"> 1. System designed to minimize potential for leakage. 2. Potential sources of ignition minimized. 3. Cell temperature maintained below flash point to eliminate possibility of an explosion. 4. Fire extinguishing system. 	Activity release depends on damage to cell HEPA filters. Maximum release from the FRP stack is about 1×10^{-2} g calcine in 0.5 hour.
4.1.22 - Failure of cell exhaust filters. Expected frequency $\sim 0.2/\text{yr}$.	<ol style="list-style-type: none"> 1. Filters not properly seated, or damaged during handling of filter or process equipment, or moisture buildup. 2. Defective filters replaced. 	<ol style="list-style-type: none"> 1. Periodic tests of filter efficiency. 	Slight increase in activity of cell off-gas to building APS.

The consequence of most of the accidents is the release of no more than a few grams of airborne calcine to the cell atmosphere. Each metric ton of spent fuel processed yields 52.5 kg of HLW calcine. The WCF cell ventilation air leaves the cell through a roughing filter and two HEPA filters ($DF = 10^7$). The cell ventilation air then is combined with the FRP HVAC air before going through the atmospheric protection system ($DF = 10^4$). Thus the DF for particles (calcine) is 10^{11} before release at the FRP stack.

A few of the accidents affect equipment in the WCF process offgas treatment system. The activity normally in the offgas stream is given in Table 4.1.22. The increase in activity due to the postulated accidents is indicated in Tables 4.1.24 and 4.1.25. The duration of any of these accidents involving equipment failures in the offgas system should not exceed 8 hours.

4.1.2.10 Waste Calcination Facility Costs

Estimates have been made, in mid-1976 dollars, of capital, operating, and leveled costs for solidification of HLW by calcination. A complete description of the cost estimate bases, assumptions, and definitions is given in Section 3.8.

Capital Costs. The capital cost estimate for the waste calcination facility is shown in Table 4.1.26 expressed in mid-year 1976 dollars. The estimate covers all capital costs specifically resulting from including the WCF as an integral part of the reference FRP. These costs also include the effect of incremental additions to utility supplies, such as electrical substation, HVAC, compressed air, and similar auxiliaries, as well as the cable, piping and other bulk materials incorporated directly into the facility. However, general FRP costs for such services as laboratories and warehousing are not allocated to the WCF.

The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation with the exception of working capital and special maintenance equipment. HLW canisters, overpacks, and consumable materials are included in operating costs. Shielding costs are included under transportation. Sampling and testing of HLW calcine are not included in the capital cost estimate.

Operating Costs. Table 4.1.27 shows the operating cost estimate for the waste calcination facility. Direct labor costs have been estimated using the manpower estimates in Table 4.1.18 and the wage factors given in Section 3.8. In addition, labor costs were increased \$400,000 to allow for major remote maintenance requirements. Miscellaneous supplies and equipment include nitric acid, ammonia, oxygen, kerosene and silver zeolite requirements. Process materials, consisting of 683 8-in. dia x 10-ft long stainless steel canisters at \$5,300 each, comprise the largest element of the operating cost. Utility costs are based on requirements shown in Table 4.1.20. Maintenance materials are estimated at 5% of process equipment costs plus 1 million dollars every ten years for calciner and furnace replacement. Overhead and miscellaneous costs are estimated using the factors given in Section 3.8.

TABLE 4.1.26. Capital Cost Estimate for the Waste Calcination Facility

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		40	3,600	500	4,100
Building and structures		500	3,000	6,100	9,100
Bulk materials		670	8,400	8,000	16,400
Site improvements		<u>10</u>	<u>100</u>	<u>100</u>	<u>200</u>
Subtotal of direct site construction costs		1,220	15,100	14,700	29,800
Indirect site construction costs	<u>320</u>	<u>240</u>	<u>5,400</u>	<u>7,100</u>	<u>12,500</u>
Total field cost	320	1,460	20,500	21,800	42,300
Architect-engineer services					<u>7,700</u>
Subtotal					50,000
Owner's cost					<u>15,000</u>
Total facility cost					65,000
Estimated accuracy range					±30%

TABLE 4.1.27. Operating Cost Estimate for the Waste Calcination Facility

Cost Element	Annual Costs, \$1000s
Direct labor	840
Process materials	3620
Utilities	100
Maintenance materials	300
Overhead	680
Miscellaneous	<u>660</u>
Total	6200 ±25%

Levelized Unit Cost. The levelized unit cost, including the levelized capital and operating segments, is shown in Table 4.1.28. The unit cost calculation assumes private ownership of the facilities and a 15-year economic life.

TABLE 4.1.28. Levelized Unit Cost Estimate for the Waste Calcination Facility

<u>Cost Element</u>	<u>Unit Cost, Kg HM</u>
Levelized capital charge	8.30
Levelized operating charge	<u>2.80</u>
Levelized total unit cost	11.10 ±35%

4.1.2.11 Waste Calcination Facility Construction Requirements

Many of the factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating the impact of construction activities.

Project Schedules and Construction Manpower. The schedule for engineering, procurement and construction of the WCF is an integral factor in the overall schedule for the FRP. The field labor force estimated for the construction of the WCF is tabulated below:

	<u>Man-hours, 1000s</u>
Manual field labor	1460
Nonmanual field labor	<u>320</u>
Total field labor	1780

Distribution Between Onsite and Offsite Costs. Onsite costs are those for all construction, materials and services provided at the site of the LWR while offsite costs are those for all services provided, equipment fabricated and/or assembled, and material purchased off of the site of the LWR. The distribution of total costs in these categories is as shown below:

	<u>Costs \$1000s</u>
Onsite	23,000
Offsite	<u>42,000</u>
Total	65,000

Site Requirements. The reference WCF is contiguous with the FRP and thus shares the overall siting requirements of the FRP. Aside from the area directly occupied by the facility (26 x 26 m), the WCF requires that a water storage facility be constructed for interim storage of the filled waste canisters. A canister shipping facility must also be constructed for off-site shipment of the canisters. These facilities, which require about 10 times the space of the WCF, are described in Section 5.4.

Water. Water used during the construction period will be approximately 22,700 m³ (6.0 x 10⁶ gal).

Construction Materials. Materials committed to facility construction are:

Concrete	6100 m ³	(8000 yd ³)
Steel	1800 MT	(2000 tons)
Copper	18 MT	(20 tons)
Zinc	1.8 MT	(2 tons)
Lumber	330 m ³	(140 MFBM)

Energy. Energy resources used during construction are estimated at:

Propane	227 m ³	(60,000 gal)
Diesel fuel	2,000 m ³	(530,000 gal)
Gasoline	1,363 m ³	(360,000 gal)
Electricity		
Peak demand	500 kW	
Total consumption	1,000,000 kWh	

Transportation Requirements

No separate transportation requirements for the WCF have been identified beyond those for the FRP.

4.1.2.12 Effects of Fuel Cycle Options

As with the vitrification process described in Section 4.1.1, the reference HLLW calcination process assumes reprocessing of LWR fuel and recycling the retrieved uranium and plutonium. An assessment of alternative fuel cycle modes as they relate to calcination yields the same information given for the WVF (Section 4.1.1.12), with the exception of the amount of PuO₂ added to each canister via the last option, uranium recycle only with plutonium to high-level waste. With the calcination process as described for the reference WCF, about 28.0 kg of PuO₂ would be added to each canister of calcine if this option were implemented, as opposed to 29.1 kg of PuO₂ per canister of HLW glass, given the same fuel cycle mode. As is the case with vitrification, considerable research and development would be required before this option, uranium recycle with plutonium to HLW, could be used with the calcination process.

A criticality safety analysis assuming 28.0 g of PuO₂ per canister was conducted for the fluidized bed calciner, its associated equipment, and its waste calcine product. During production of the calcine, criticality safety can be assured by the finite sizes of the equipment. If dry calcine were stored in an infinitely long 60-in. diameter cylinder with full water reflection around it, the k_{eff} for the canister would be 0.725 ± 0.007 ; the canister would be critically safe.

The possibility of criticality in the hold feed hopper and bed dump hopper used in the fluidized bed calciner system was evaluated. Both hopper vessels consist of thirteen 10 cm (4-in.). Schedule 40S pipes, each 2.9 m (113 in.) long, arranged in a 50 x 60 cm (20 x 24 in.) water-filled cooling jacket. Distributor cones at top and bottom hold additional calcine material. This particular system represented by these hoppers was studied because it represents a heterogeneous lattice of calcine-filled tubes interstitially moderated and fully reflected by water. The calculated k_{eff} is 0.25 for this system, so there is no criticality problem in

this equipment. The same is true after the calcine is loaded into canisters. When the calcine is loaded into a 20 cm (8 in.) Schedule 40S canister, 3 m (120 in.) long, and the canister is fully reflected by water, concrete, graphite, granite shale, dry rock salt, or saturated brine solution, the k_{eff} values range from 0.14 to 0.29. Hence, single isolated cylinders of calcine will be critically safe under any foreseeable conditions. Some limitations, however, would probably have to be imposed against stacking more than an estimated 50 calcine canisters closely together. Such stacking does not occur anywhere in the HLW management system.

This fuel cycle option requires that the PuO_2 be homogeneously distributed in the calcine at all times. Unlike the vitrification process, no mechanism has been identified which could credibly cause large accumulations of PuO_2 in the WCF.

4.1.3 Other Alternatives

A large amount of R&D has been done in HLLW solidification and the investigations are continuing. As part of this R&D, alternatives to glass or calcine as the final waste form are being studied. Encouraging progress is being made, particularly in the use of crystalline waste forms and metal matrices. The goal of most of this work is improved inertness of the waste form. It is recognized that these alternative waste forms involve increased operating costs, but the investigations are nonetheless prudent. They assure a continual advancement in the state-of-the-art.

4.1.4 Physical Protection and Safeguard Requirements for High Level Liquid Waste (HLLW) Solidification

Three recycle modes produce HLLW which must be solidified: recycle of both plutonium and uranium, the uranium-only recycle in which plutonium is stored separately, and the uranium only recycle mode where plutonium is solidified with the HLLW. With the first two options, the solidified waste is a very unattractive target for theft as a source of material for weapons. The waste contains essentially all of the fission product activity from the spent fuel in the waste but the plutonium content of the waste is reduced to less than 1% of that in the spent fuel. In the uranium-only recycle mode in which plutonium is solidified along with the HLLW, the solidified waste is a more attractive target for theft as a source of materials for weapons because it does contain all of the plutonium from the spent fuel. However, because the waste contains essentially all of the fission product activity and would require sophisticated chemistry to extract its plutonium, the waste would still be an unattractive target for theft.

SHLW is not readily accessible in any case because:

- remote operation is required to handle equipment and canister
- massive biological shielding is required to attenuate canister surface dose rates
- facility design features protect against severe natural occurrences.

The consequences to the public of sabotage are expected to be very small. Should a canister of waste be ruptured by explosives, the radioactive material dispersed would be confined

largely within the plant area. An explosion among process vessels and lines before solidification of the waste would also present no significant hazard to the public since the radioactive material would be confined within the plant.

Solidification of HLLW would occur in vital areas within the FRP site. The physical protection required for these areas is available to meet all safeguard requirements for this material from either fuel cycle.

REFERENCES FOR SECTION 4.1

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5. "Radioactive Waste Management." Proceedings of the Third International Conference on the Peaceful Uses of Atomic Energy, Geneva, August 31 - September 9, 1964, United Nations, New York, Vol 14, pp. 219-368, 1965.
6. Proceedings of the Symposium on Management of Radioactive Wastes from Fuel Reprocessing, Paris, November 27 - December 1, 1972. Organization for Economic Cooperation Development, Washington, DC, 1973.
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4.2 PACKAGING OF FUEL RESIDUE

4.2 PACKAGING OF FUEL RESIDUE

Fuel residue is generated in the course of reprocessing LWR fuels when fuel assemblies are sheared into short (5- to 13-cm) lengths and leached with hot nitric acid. The residue includes short lengths of Zircaloy fuel cladding (hulls) and fuel assembly hardware, comprising support rods, poison rods, massive end fittings, fuel support grids, assorted springs and spacer elements.

The type and amounts of materials found in the residue depend somewhat upon the fuel fabricator; however, the residue generally includes Zircaloy, 304 stainless steel, and Inconel-718 in the weight ratios of about 24/4/1, respectively. The average total fuel residue per MTHM, assuming a reactor capacity of 1/3 BWRs and 2/3 PWRs, is composed of about 266 kg Zircaloy, 44 kg stainless steel, and 11 kg Inconel. The acid-leached fuel cladding sections are expected to contain about 0.05% of the original fuel. The average density of the untreated hulls is estimated to be 1 g/cm^3 , which corresponds to a volume of about $0.3 \text{ m}^3/\text{MTHM}$. Zirconium, the chief alloying element in Zircaloy, is known to be pyrophoric when finely divided.⁽¹⁾

The radioactivity associated with fuel residue includes the activation products of Zircaloy, stainless steel, and Inconel, as well as fission products and transuranic nuclides from undissolved fuel. Some of the radioactivity is located on the surface and in the surface oxide and some is uniformly distributed throughout the metal. This uniformly distributed activity comes from activation of alloying elements and from diffusion of fission-produced tritium. The heat generation rate of fuel residue after 1.5 years cooling is about 225 W/1000 kg.⁽²⁾ Radioactivity associated with the cladding hulls and hardware and the annual quantities produced at a 2000 MTHM/yr FRP are summarized in Table 4.2.1. Additional details are presented in Section 3.3.

The fuel residue treatment facility is part of the reference fuel reprocessing plant (FRP), as noted by the shaded area in Figure 4.2.1. The alternative treatment processes selected for consideration include 1) packaging without compaction, 2) packaging preceded by mechanical compaction, and 3) packaging preceded by compaction by melting. The first alternative is simplest to implement and is essentially commercial practice. The second and third alternatives are considered technically feasible although demonstration of these processes is incomplete.⁽²⁾

4.2.1 Fuel Residue Packaging Without Compaction

Obvious incentives exist for compacting the fuel residue prior to packaging. However, the simplicity of the concept for packaging the hulls without treatment strongly recommends it for remote hot cell operations.

4.2.1.1 Process Alternatives for Fuel Residue Packaging Without Compaction

Viable process options include:

1. Monitor for undissolved fuel, dry, and package with hardware.
2. Monitor for undissolved fuel, dry, separate hulls from fines and hardware. Deactivate fines and package them with hulls. Package hardware separately.

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4.2.2

TABLE 4.2.1. Activity in Untreated Fuel Residue^(a)

Radionuclide	Ci/yr	
	Cladding Hulls(b)	Assembly Hardware(c)
<u>Fission products</u>		
³ H	1.3 x 10 ⁵	
⁹⁰ Sr + ⁹⁰ Y	1.2 x 10 ⁵	
⁹⁵ Zr + ⁹⁵ Nb	1.1 x 10 ⁴	
¹⁰⁶ Ru + ¹⁰⁶ Rh	3.8 x 10 ⁵	
¹³⁴ Cs + ¹³⁷ Cs + ^{137m} Ba	3.0 x 10 ⁵	
¹⁴⁴ Ce + ¹⁴⁴ Pr	4.8 x 10 ⁵	
Other Fission products	1.0 x 10 ⁵	
Total	1.5 x 10 ⁶	
<u>Actinides</u>		
²³⁹ Pu	3.6 x 10 ²	
²⁴¹ Pu	1.8 x 10 ⁵	
Other Pu	2.8 x 10 ³	
²⁴² Cm + ²⁴⁴ Cm	1.7 x 10 ⁴	
Other Actinides	9.2 x 10 ²	
Total	2.0 x 10 ⁵	
<u>Activation Products</u>		
⁵⁵ Fe	1.8 x 10 ⁵	8 x 10 ⁶
⁶⁰ Co	2.0 x 10 ⁵	8 x 10 ⁶
⁹⁵ Zr + ⁹⁵ Nb	5.6 x 10 ⁵	
Other Activation products	2 x 10 ⁴	8 x 10 ⁶
Total	7.4 x 10 ⁵	2.4 x 10 ⁷

a. Based on waste characterization Table 3.3.28 assuming uranium and plutonium recycle, 2000 MTHM/yr reprocessed 1.5 years out-of-reactor.

b. Volume - 532 m³/yr; density - 1000 kg/m³.

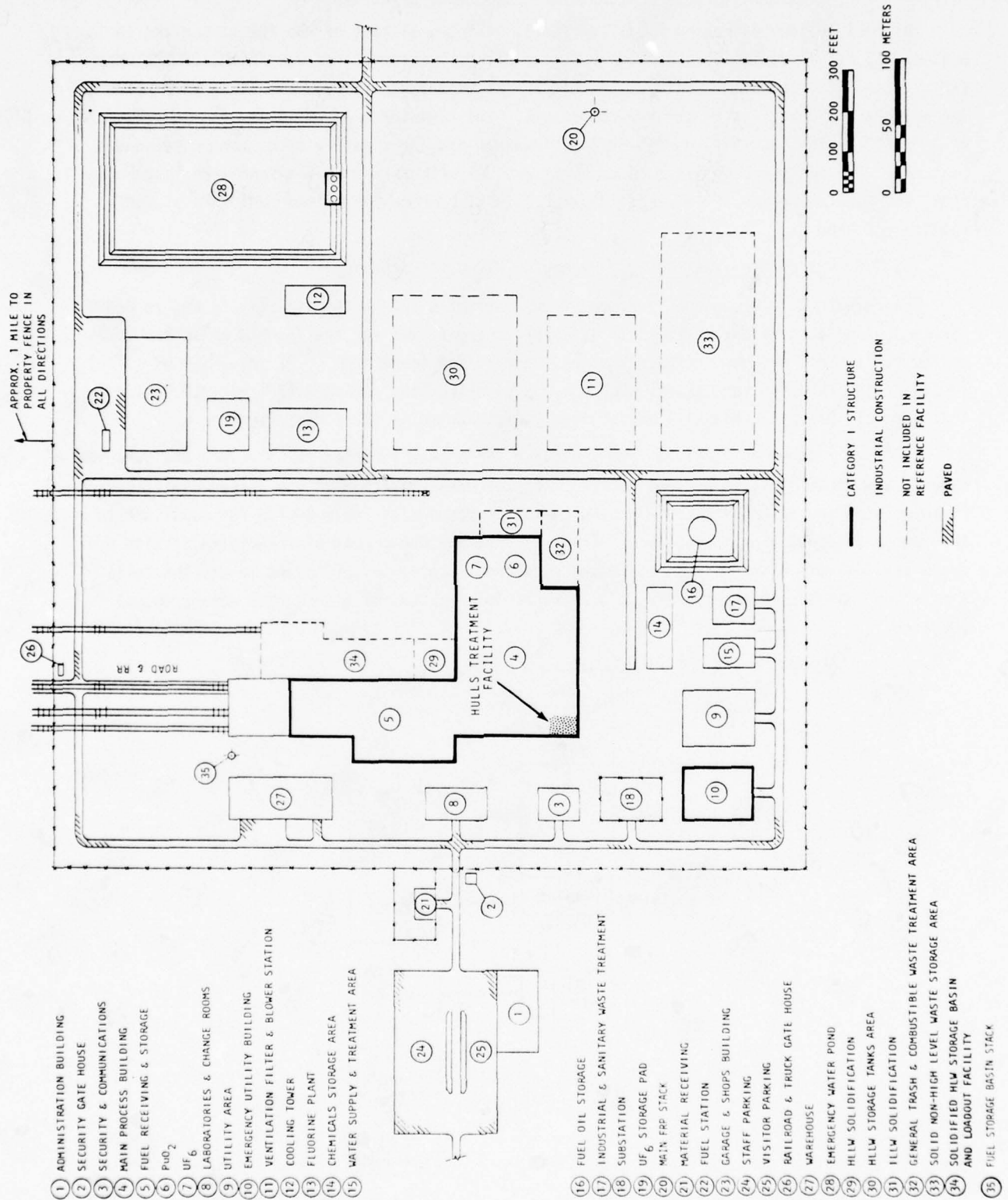
c. Volume - 112 m³/yr; density - 1000 kg/m³.

3. Monitor for undissolved fuel, dry, blend with inert matrix material (sand), and package with hardware.

All three options are currently feasible. Option 1 represents the most economical and simple approach, with minimal safety risk. Option 2 produces the optimum product, but with maximum complexity of equipment and operations. Separate packaging of hulls and hardware is beneficial if TRU contamination of the hardware can be prevented. Separation of massive hardware prior to leaching may be justified to reduce the volume of dissolver required. Separation of the fines into a discrete unit will require their deactivation by oxidation, dissolution, matrix formation, or other process.

Option 3 is a compromise between Options 1 and 2. It was chosen as the reference process primarily because sufficient data are not available concerning the amount and pyrophoric nature of Zircaloy fines generated from shearing irradiated fuel assemblies. Deactivation of the hulls through matrix formation was considered desirable to assure that no fires would occur from ignition of Zircaloy fines during processing and storage. Dry sand was chosen for the matrix material because of its fluidity, inertness, availability, and ease of handling. Hulls canisters would contain about equal weights of hulls and sand. Dry sand is required to avoid the radiolytic decomposition of associated water that could pressurize the containers.

4.2.3



4.2.4

4.2.1.2 Design Basis for the Fuel Residue Packaging Facility

The fuel residue packaging facility (FRPF), an integral part of the FRP (described in Section 3.2.3), is designed to package remotely all fuel assembly residue from a 2000-MTHM/yr FRP. Table 4.2.1 shows the activity present in the untreated residue; the table also notes the volumes and densities of the two components. Two canisters, 76 cm (2 1/2 ft) in diameter by 3 m (10 ft) long and filled with hulls, hardware, and inert matrix sand, can be processed each day. The canisters are assumed to be compatible with transportation and with interim and final storage facilities. One year of operation will produce 480 filled canisters of fuel residue and sand.

4.2.1.3 Process for Fuel Residue Packaging Without Compaction

The reference fuel residue treatment flow diagram is shown schematically in Figure 4.2.2. For reasons of economy and criticality it is necessary to monitor the leached hulls for undissolved fuel. This may be done by measuring the 2.18 MeV gamma from ^{144}Pr (daughter of ^{144}Ce) remaining in the dissolver basket. Table 4.2.2 describes the packaged fuel residue, assuming that assembly hardware and hulls are uniformly distributed in 480 canisters.

The fuel residue as received from the dissolver basket is dried to 1) reduce the pyrophoricity of any Zircaloy fines present and 2) eliminate pressurization of the sealed canister from radiolysis of the adsorbed water. During normal processing of fuels cooled for about one to two years, no special drying equipment is necessary; the decay heat of associated fission products and activation products in stainless steel and Inconel is sufficient to dry the hulls. A moisture analyzer checks the effluent from the drier basket to ensure that water removal is complete.

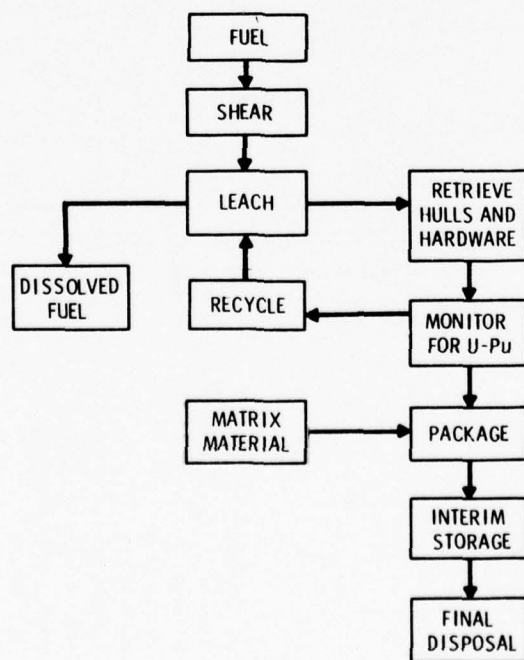


FIGURE 4.2.2. Flow Diagram for Fuel Residue Without Compaction

4.2.5

TABLE 4.2.2. Description of Packaged Fuel Residue

Volume ^(a)	670 m ³ /yr
Density	970 kg/m ³
$\frac{\text{Volume Treated}^{(a)}}{\text{Volume Untreated}}$	1.04
Canisters ^(b) /yr	480
Canister surface dose rate	>10 R/hr
Radioactivity as fraction of input ^(c)	1.0

a. Volume of waste canisters.

b. 75 cm dia x 3 m long.

c. See Table 4.2.1.

Neither heat production nor radiation levels impose severe limits on canister dimensions. However, the design must be compatible with shipping facilities and with the final repository handling requirements. The assumed canister handling capability at the geologic repository, 76 cm (30 in.) in diameter by 3 m (10 ft) long, limits the canister size. The reference fuel residue canister is a stainless steel cylinder having these dimensions. A canister filled to a depth of 2.9 m (9 ft 8 in.) with hulls, hardware, and sand will have the capacity to contain the residue produced from processing 4.2 MTHM. Automatic, remote welding, such as is being done routinely in the nuclear industry, is the best method for closure of the filled canisters. Prior to welding, the canister should be flushed with helium; a helium leak tester can then be used to determine the integrity of the closure.

4.2.1.4 Description of the Fuel Residue Packaging Facility

This section outlines the facility requirements for a fuel residue packaging facility. This facility receives the leached fuel residue remaining in the FRP dissolver after dissolution of the chopped fuel, packages it in steel canisters, and prepares the canisters for storage or shipment to a repository.

General Description. The facility for packaging without compaction is centered around a remotely operated cell 7.3 m (24 ft) wide, 12.2 m (40 ft) long, and 9.1 m (30 ft) high. It is controlled and operated from the operating gallery located behind 1.2 m (4 ft) concrete shielding walls fitted with shielding windows and manipulators.

Because this facility is an integral part of the FRP, certain services and auxiliary systems required for its functioning, such as maintenance and utilities, are part of the primary facility and are not detailed in this section. Figures 4.2.3 through 4.2.6 show the layout and equipment arrangement, which are the basis for the cost estimate.

The facility is located in the FRP and is a Category 1 structure. The fuel residue packaging cell is provided with a stainless steel pan that covers the floor and with radiation- and corrosion-resistant wall coatings. The decontamination station walls and floors, including the shielding door surfaces and the floor sumps, are lined with stainless steel.

4.2.6

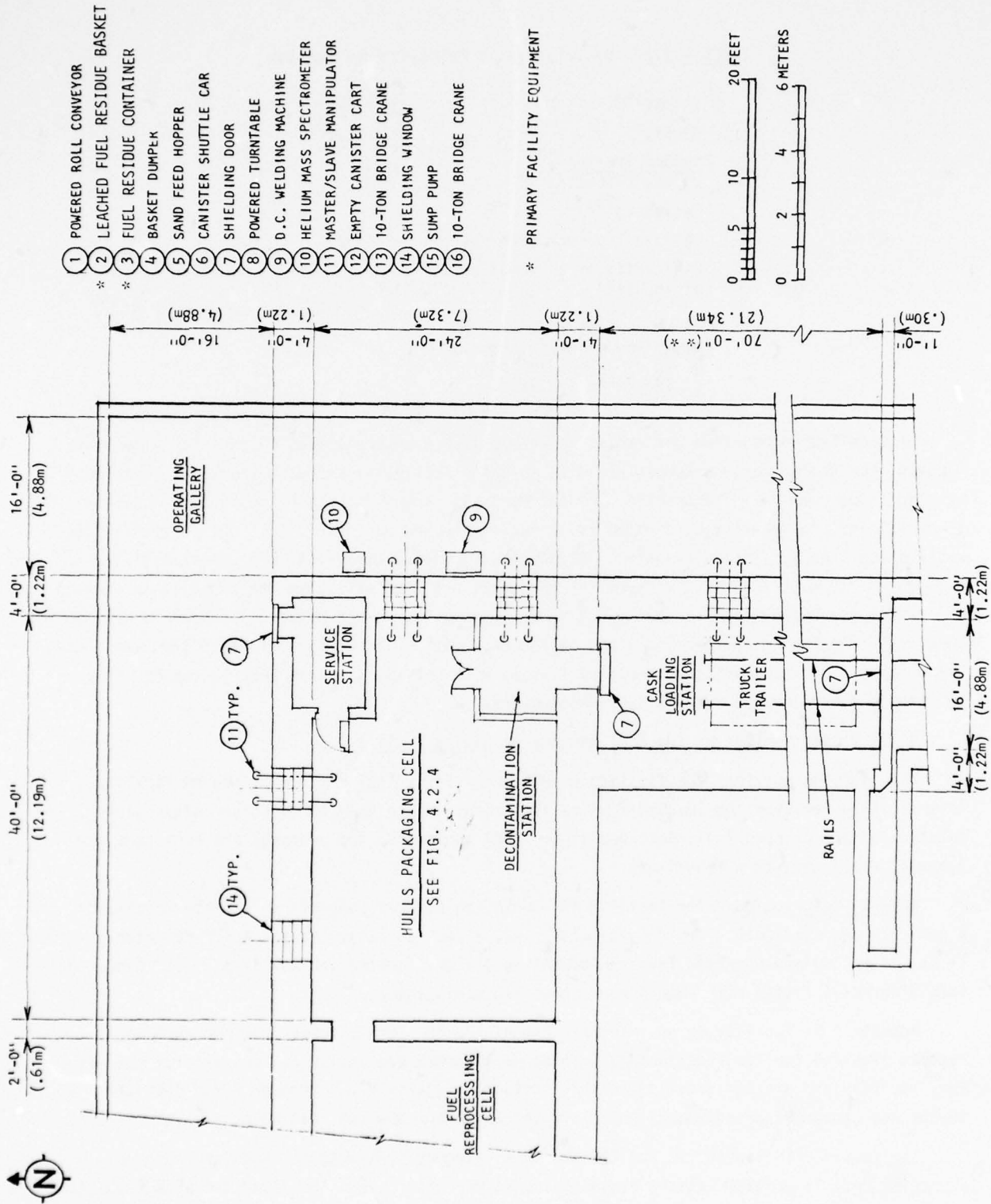


FIGURE 4.2.3. Fuel Residue Packaging Without Compaction, General Plan

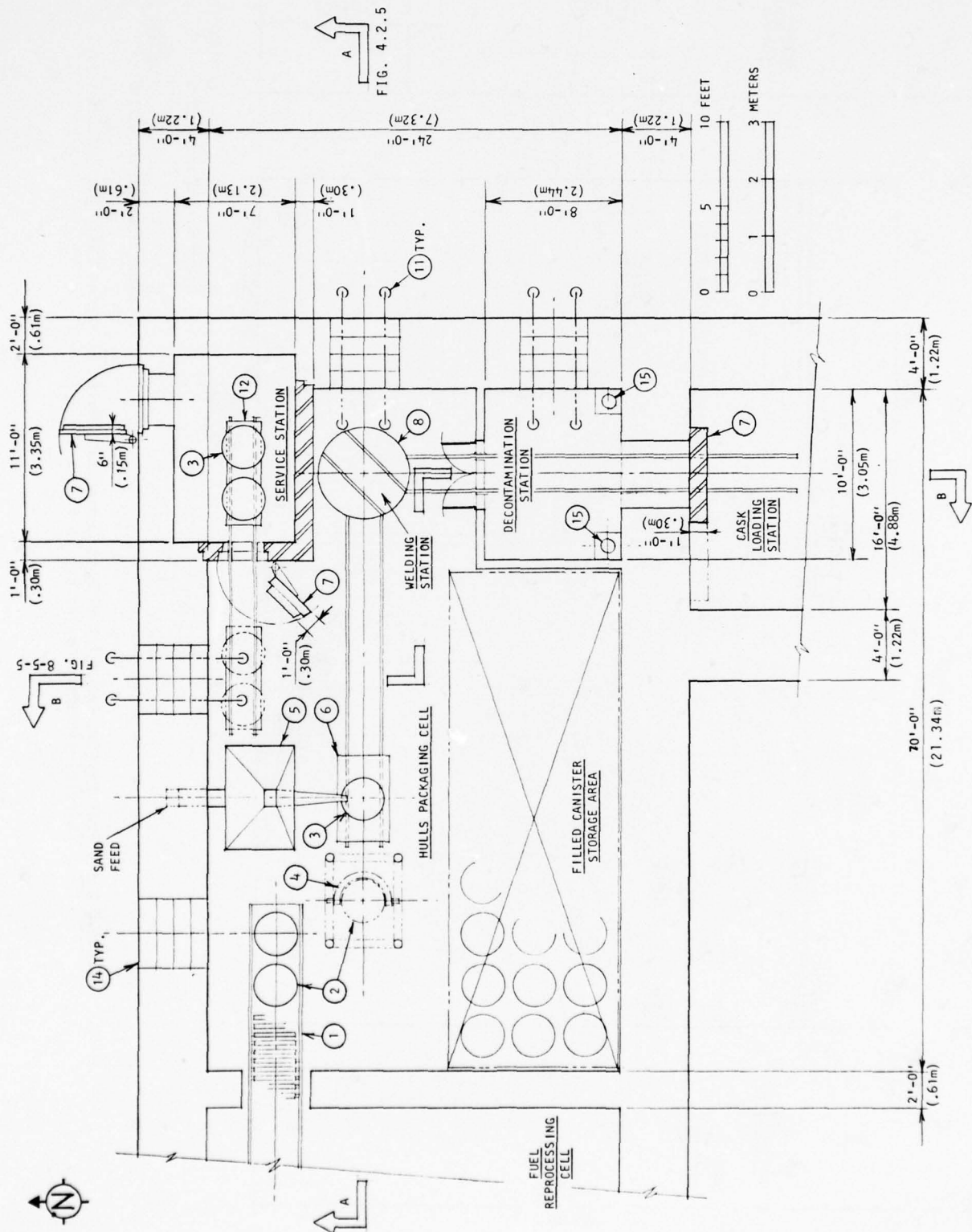


FIGURE 4.2.4. Fuel Residue Packaging Without Compaction, Hulls Packaging Cell Plan
(Circled numbers refer to key in Figure 4.2.3.)

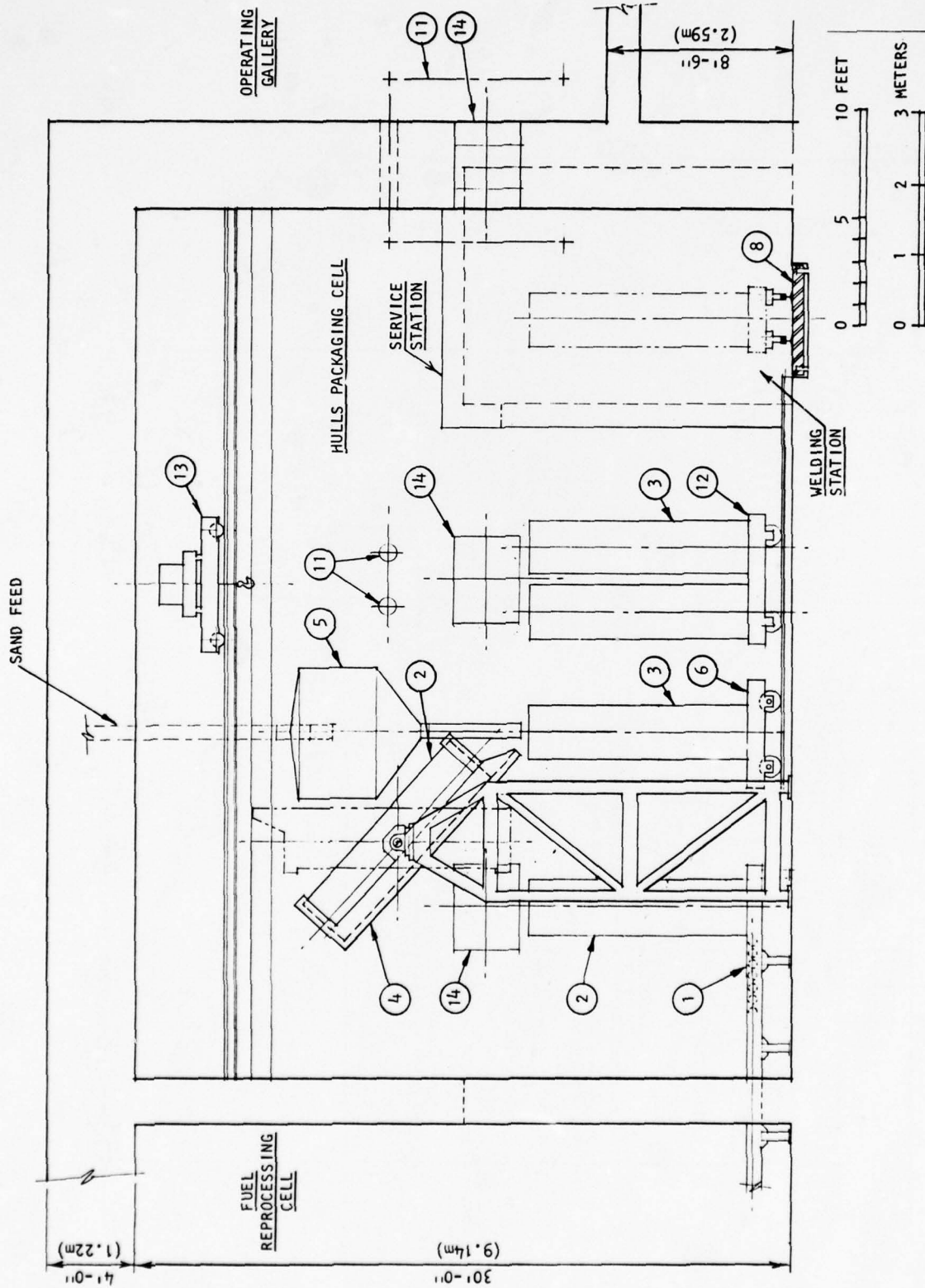


FIGURE 4.2.5. Fuel Residue Packaging Without Compaction, Hulls Packaging Cell, Section A-A
(Circled numbers refer to key in Figure 4.2.3.)

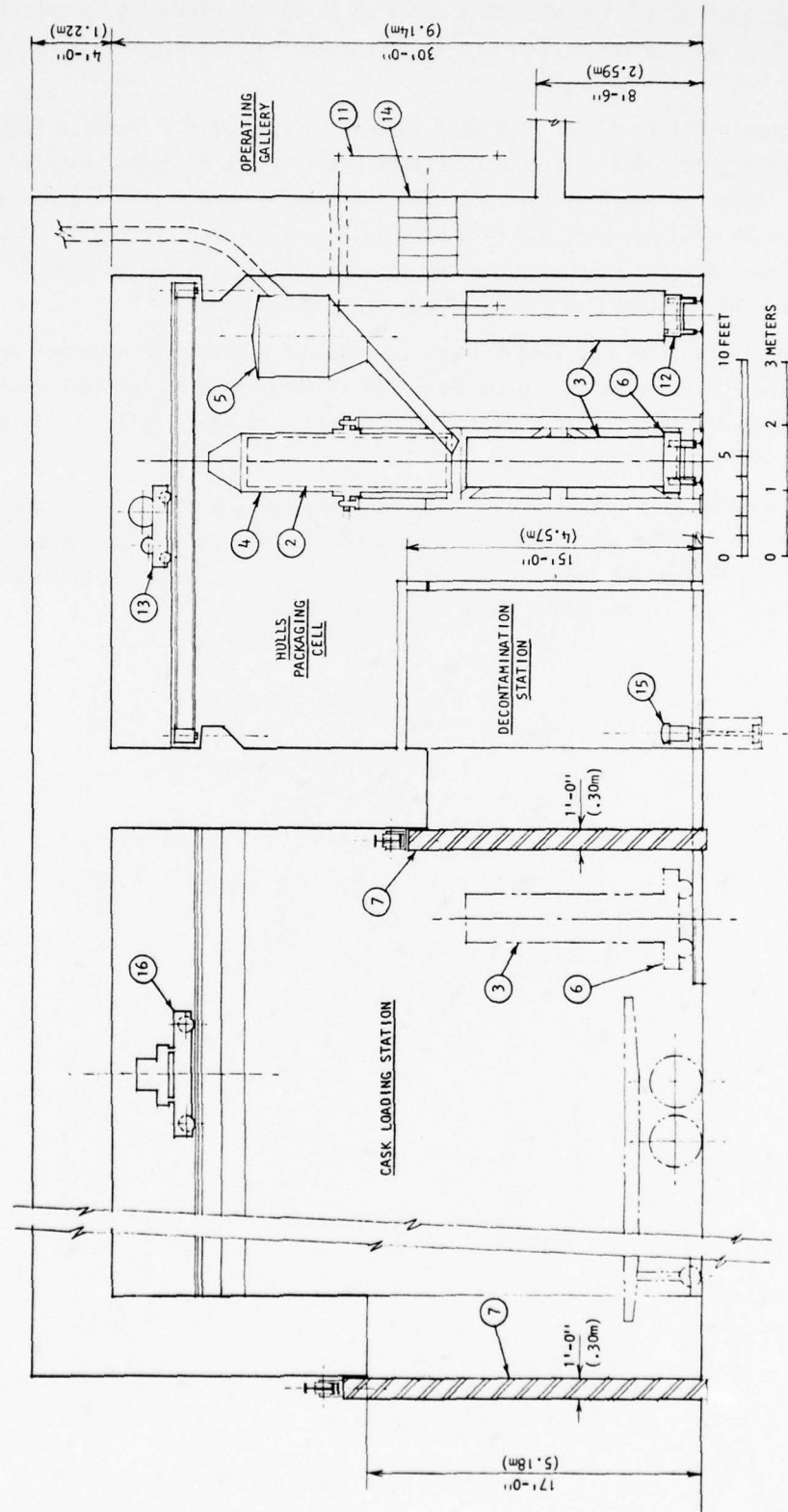


FIGURE 4.2.6. Fuel Residue Packaging Without Compaction, Hulls Packaging Cell, Section B-B
(Circled numbers refer to key in Figure 4.2.3.)

4.2.10

Major Equipment. The equipment required to do the packaging is described in the following paragraphs in the sequence of operation for packaging, container closure, decontamination and shipping.

A powered roller conveyor is used to move baskets of fuel residue into the packaging cell. The 10-ton bridge crane secures each basket within a basket dumper mounted on steel supports. When the dumper is remotely inverted, the fuel residue drops into a canister through a metering device, which also controls the flow of sand from a hopper. Figure 4.2.7 is a diagram of the fuel residue canister. An air-operated vibrator applied to the outside of the canister helps achieve a good settling and mixing of the residue and sand.

When the canister has been filled, the shuttle car and the canister are moved to the welding station for the capping and welding of a lid and for a helium leak detection test. The shuttle car, an electrically powered vehicle, rides on steel rails and is operated remotely from the gallery.

The welding station, located at the east side of the cell, consists of a power turntable to secure the shuttle car and an overhead support frame to hold the electrode rod, argon supply line, helium test probe, and a stack of container lids. The work is rotated while the welding and the leak testing equipment above remain stationary.

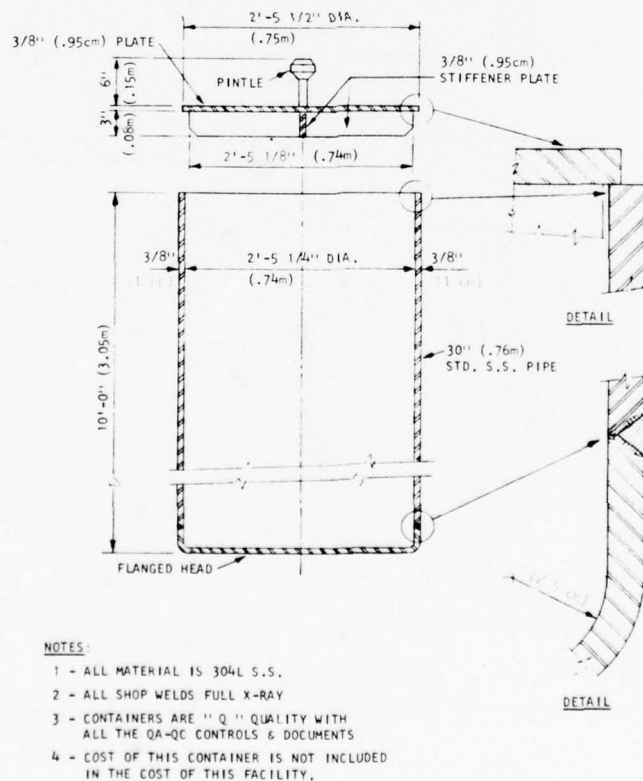


FIGURE 4.2.7. Fuel Residue Canister

4.2.11

The welding process is by automatic gas-tungsten arc with no filler metal. Only one pass is required to complete the weld and start the helium leak test.

When the canister is brought into the shipping area, it is monitored for contamination. Here, if needed, the canister is sprayed with decontamination solution to remove the contamination and reduce the potential of contaminating the cask and the interim storage facility. Only clean canisters are transferred to the cask loading station. The canister is handled and loaded into the cask remotely from the operating station. All other routine operations such as equipment maintenance and cask placement, are performed by direct contact inside the cask loading station with the shielding door to the packaging cell closed.

Shielding and Remote Handling Equipment. The process equipment is located behind four foot shielding walls. Manipulator through-tubes and similar equipment will require shielding equivalent to 25 cm (10 in.) of lead.

4.2.1.5 Operating and Maintenance Requirements for the Fuel Residue Packaging Facility

The process equipment will be operated on an intermittent basis when an accumulated quantity of rinsed hulls and hardware sufficient to fill one canister (1.3 m^3) becomes available. Up to 2 canisters/day will be produced. Operation will be on the basis of 2 shifts/day, 5 days/week. The welding station will operate on a 1 shift/day basis, 5 days/week.

Staffing. Staffing requirements are given in Table 4.2.3.

TABLE 4.2.3. Staffing Requirements for Fuel Residue Packaging Without Compaction

<u>Job Description</u>	<u>Personnel Required, man-yr/yr</u>
Operators	6
Radiation monitors	1
Maintenance craftsmen	1

Supplies and Utilities. Table 4.2.4 shows the estimated supplies and utilities required for hulls packaging.

TABLE 4.2.4. Supply and Utility Requirements for Fuel Residue Packaging Without Compaction

<u>Item</u>	<u>Use Rate</u>	<u>Annual Requirement</u>
Electricity	10 kW	25,000 kWh
Sand	2600 kg/day	650 MT
Argon	$60 \text{ m}^3/\text{day}$	7000 m^3
Helium	$30 \text{ m}^3/\text{day}$	700 m^3
Canisters	2/day	480

Hazardous Materials. A small quantity of Zircaloy fines will be associated with the cladding hulls. The hazards associated with Zircaloy fines are discussed in Sections 4.2.1.9 and 4.2.2.9.

4.2.1.6 Secondary Radioactive Wastes for the Fuel Residue Packaging Facility

Table 4.2.5 lists the secondary wastes produced in this treatment task.

TABLE 4.2.5. Secondary Radioactive Wastes from Fuel Residue Packaging Without Compaction

Description	Volume, m ³ /yr	Radioactivity Factor ^(a)
Combustible and compactable waste	40	All 1×10^{-6}
Wet waste	1	All 1×10^{-4}
Failed equipment	0.2	All 1×10^{-4}

a. Fraction of input activity (Table 4.2.1) in secondary wastes.

4.2.1.7 Emissions from the Fuel Residue Packaging Facility

Estimated emissions are given in Table 4.2.6. An estimate of the integrated annual release due to minor accidents (Section 4.2.1.9) for this facility is also included in Table 4.2.6. It was developed by weighing the minor accident releases by their expected frequencies and summing the quantities for all identified minor accidents. In addition, a contingency was included in the integrated release to account for unidentified minor accidents and to compensate for the uncertainty in expected frequency information.

TABLE 4.2.6. Fuel Residue Packaging Emissions

Emission	Description	Annual Quantity	Radioactivity Release Factor
Gaseous	Cell ventilation air	$2 \times 10^8 \text{ m}^3$	All 1×10^{-13}
	Minor accident integrated annual release		³ H 4×10^{-6} All others 4×10^{-13}

a. Fraction of input activity (Table 4.2.1) released to atmosphere. Includes DF of 10^4 for particulates in APS. Released over 300 days/year.

4.2.1.8 Decommissioning Consideration for the Fuel Residue Packaging Facility

The useful life of the facility for packaging without compaction is expected to equal that of the reprocessing facility, 30 years. For final disposal the equipment would be treated as TRU-contaminated waste.

4.2.1.9 Postulated Accidents for the Fuel Residue Packaging Facility

Zircaloy is a potential pyrophoric hazard. However, spontaneous ignition of zirconium or Zircaloy will occur only if the material is a finely divided powder. Information pertinent to particle size, form, and ease of ignition is given in Table 4.2.7. Almost all data on the pyrophoricity of zirconium have been obtained with unirradiated material. It is unlikely that a significant difference exists between the pyrophoric behavior of irradiated and nonirradiated Zircaloy since the alloy is not altered chemically by irradiation. However, the absence of direct experimental verification requires a conservative approach to the handling and storage of Zircaloy fines produced by the chopping of fuel assemblies.

The ductility of Zircaloy fuel rods decreases with increase in fuel burnup. The amount of fines produced during shearing or chopping will be higher with irradiated than nonirradiated, less brittle material.

TABLE 4.2.7. Pyrophoricity of Zirconium

Metal Form	Burning Characteristic
Fine powder	<62 μm , explosive ⁽³⁾ <10 μm , explosive ⁽⁴⁾
Coarse powder	>125 μm , <840 μm , hazardous ⁽³⁾ >10 μm , <853 μm , explosion risks ⁽⁴⁾
Chips, cuttings	0.013 cm thick, easily ignitable ⁽⁵⁾
Damp powder	3-16% H_2O spontaneous combustion and explosion ⁽⁵⁾

For packaging without compaction, the greatest fire hazard exists during transfer of hulls from the dissolver basket via a hopper to the hull storage canister. Only the fines will burn; studies have shown that ignition of fines in contact with hulls does not ignite the hulls. The hulls, however, are a possible source of sparking. The packaging without treatment alternative employs sand as a matrix material (see Section 4.2.1.1). Dry sand added (on an equal weight basis) to the hulls residue will effectively prevent Zircaloy fire by preventing fines separation and also by its diluting effect.

A postulated Zircaloy accidental fire during packaging without compaction is presented in Table 4.2.8. The consequences of a Zircaloy fire would depend upon the quantity of material involved. Segregation and ignition of all the pyrophoric fines present in one dissolver basket, estimated to be no more than about 1 kg (2.2 lb), is the maximum potential fire. The absence of other combustible material would prevent the spread of the fire beyond the immediate area. Contact of the burning fines with water could cause a hydrogen explosion; however, a source of water is difficult to postulate. All tritium from the burned Zircaloy would be released through the FRP stack. The heat release would be about 3.3 kWh/kg (5200 Btu/lb) Zircaloy. No accidents that could be classified as moderate or severe accidents could be realistically postulated for this technology.

TABLE 4.2.8. Fuel Residue Packaging Facility Minor Accidents

Accident No. and Description	Sequence of Events	Safety Systems	Release
4.2.1-Zr fines fire. Estimated frequency ~1/yr.	1. Fines generated in the chop-leach operation. 2. Spark, or other heat source, ignites fines in basket. Spontaneous ignition possible if drying is incomplete. 3. Fire releases volatile activity to process cell atmosphere.	1. Small inventory of fines. 2. Predrying of hulls and fines prevents ignition. 3. Blending with sand matrix. 4. Inert atmosphere for welding operations (with alarm to detect loss).	1 kg zirconium fines burns releasing volatile activity to process cell atmosphere in 0.5 hour. ³ H would remain gaseous while Cs, Te, Ru and Rb are expected to form particles. All others are expected to either not volatilize or would plate out before reaching the facility filters.

Criticality considerations require that the total undissolved fuel contained in an individual hulls canister be limited to some fraction (Barnwell specifies 0.75)⁽⁶⁾ of the minimum critical mass. The minimum critical mass of hulls is dependent upon the initial enrichment of the particular fuel being processed. Based on a water-reflecting sphere, the minimum critical mass from UO₂-H₂O mixture at 5% ²³⁵U is 1.56 kg ²³⁵U, or 31.2 kg total uranium; for 4% ²³⁵U, the minimum critical mass is about 2 kg ²³⁵U, or 50 kg total uranium. A higher value is found for fuels of lower initial enrichment. The plutonium content in irradiated fuel need not be considered since unirradiated fuel reactivity is limiting. In the case of mixed oxide fuels, for a homogeneous mixture of PuO₂ + natural uranium UO₂ + H₂O at 5 wt% Pu (containing 20% ²⁴⁰Pu) the minimum critical mass is estimated to be 26 kg PuO₂ + UO₂, based on a water reflected sphere; at 4 wt% Pu, it is about 35 kg PuO₂ + UO₂. Table 4.2.9 shows the percentage of undissolved fuel that may remain with the cladding for these enriched uranium and mixed oxide fuels, assuming the packaging without compaction treatment alternative. The percentage of fuel expected to remain undissolved is at least an order of magnitude lower than these values.

TABLE 4.2.9. Allowable Percentage of Undissolved Fuel for Subcritical Fissionable Material Content in Canisters of Uncompacted Fuel Residue

Fuel Enrichment	Allowable Undissolved Fuel, %	
	Uncompacted Cladding and Hardware	Uncompacted Cladding Only
4% ²³⁵ U	1.2	0.99
5% ²³⁵ U	0.75	0.62
4% Pu	0.84	0.69
5% Pu	0.62	0.51

4.2.1.10 Costs for the Fuel Residue Packaging Facility

Estimates of capital, operating, and levelized costs are presented in mid-year 1976 dollars. A complete description of the cost estimate bases, assumptions, and definitions is given in Section 3.8.

Capital Cost. The capital cost estimate for this facility is shown in Table 4.2.10, expressed in mid-year 1976 dollars. The estimate covers all capital costs specifically resulting from its inclusion as an integral part of the FRP described in Section 3.2.3. These costs also include the effect of incremental additions to utility supplies, such as electrical substation, HVAC, compressed air, and similar auxiliaries, as well as the cable, piping and other bulk materials incorporated directly into this facility. However, general FRP costs for such services as laboratories and warehousing are not allocated to the fuel residue packaging facility.

The total capital cost includes all plant-related costs incurred from the start of engineering to the start of commercial operation, excluding only working capital.

TABLE 4.2.10. Fuel Residue Packaging Facility Capital Cost Estimate

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		20	2,400	200	2,600
Buildings and structures		99	820	1,230	2,050
Bulk materials		80	1,800	1,000	2,800
Site improvements		1	20	10	30
Subtotal of direct site construction costs		200	5,040	2,440	7,480
Indirect site construction costs	55	44	890	1,220	2,110
Total field cost	55	244	5,930	3,660	9,590
Architect-engineer services					1,900
Subtotal					11,490
Owner's cost					3,410
Total facility cost					14,900
Estimate accuracy range					±30%

Operating Cost. The reference facility's annual operating cost is shown in Table 4.2.11. Direct labor costs are based on manpower estimates given in Table 4.2.3. Process materials consist of 480 canisters, costing about \$8000 each in lots of 100 or more, and dry sand. Estimates for utilities are based on requirements also shown in Table 4.2.4. Annual maintenance materials costs are estimated at 2% of the initial equipment investment. Overhead and miscellaneous costs are based on factors described in Section 3.8. The estimates for the miscellaneous items are assumed to include all unidentified operating costs. The costs of taxes, insurance, and interest, however, are included in the capital segment of the levelized unit cost.

TABLE 4.2.11. Fuel Residue Packaging Facility Operating Cost Estimate

Cost Element	Annual Costs, \$1000
Direct labor	150
Process materials	3850
Utilities	10
Maintenance materials	50
Overhead	200
Miscellaneous	40
Total	4300 $\pm 25\%$

Levelized Unit Cost. The levelized unit cost, including levelized capital and operating costs, is shown in Table 4.2.12. The unit cost calculation assumes private ownership of the facilities. Separate costs are shown for facilities shipping the canisters by truck or by rail since a special shipping facility costing \$900,000 would be required to handle rail casks. The operating costs for a rail or truck facility are not significantly different.

TABLE 4.2.12. Fuel Residue Packaging Facility Levelized Unit Cost Estimate

Cost Element	Unit Cost, \$/kg Hm	
	Truck Shipment	Rail Shipment
Levelized capital charge	1.90	2.00
Levelized operating charge	2.10	2.20
Levelized total unit cost	4.00 $\pm 25\%$	4.20 $\pm 25\%$

4.2.1.11 Construction Requirements for the Fuel Residue Packaging Facility

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information which follows provides a basis for evaluating the impact of construction activities.

4.2.17

Project Schedules and Construction Manpower. The schedule for engineering, procurement, and construction of this facility is an integral factor in the overall schedule for the FRP. This schedule is described in Section 3.2.3.7. The field labor force estimated for the construction phase is tabulated below:

	Man-hours, 1000s
Manual field labor	244
Nonmanual field labor	<u>55</u>
Total field labor	299

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials, and services provided at the site of the FRP. Offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is as shown below:

	Costs, \$1000s
Onsite	4,400
Offsite	<u>10,500</u>
Total	14,900

Site Requirements. The facility will share the same site as the FRP. No additional site requirements beyond those for the FRP are identifiable.

Water. About 4200 m³ (1.1 x 10⁶ gal) of water are required during the construction period.

Construction Materials. Materials committed to facility construction are:

Concrete	2,000 m ³	(2,600 yd ³)
Steel	590 MT	(650 tons)
Copper	4.5 MT	(5 tons)
Zinc	.9 MT	(1 ton)
Lumber	140 m ³	(60 MFBM)

Energy. Energy resources used during construction will be:

Propane	42 m ³	(11,000 gal)
Diesel Fuel	340 m ³	(90,000 gal)
Gasoline	250 m ³	(66,000 gal)
Electricity:		
Peak demand	270 kW	
Total consumption	180,000 kWh	

Transportation Requirements. No separately defined transportation requirements for the facility have been identified beyond those for the FRP.

4.2.1.12 Effects of Fuel Cycle Options

Treatment of fuel residue in the reference facility is based on reprocessing of LWR fuel and recycling the recovered uranium and plutonium. The effects of alternative fuel cycles on treatment of fuel residue are discussed below.

No Recycle. No treatment of fuel residue is required for this option since residue is not generated if fuel is not reprocessed.

Uranium Recycle Only, with Plutonium to a Repository. No change in the treatment of fuel residue from the basic case is expected for this fuel cycle option.

Uranium Recycle Only, with Plutonium to HLW. This option requires the same facility for treatment of fuel assembly residue as the basic case.

4.2.2 Mechanical Compaction of Hulls

The incentive for compaction of hulls is the reduction of the required volume for storage, thus lowering the cost of containers, shipment, and final storage or disposal. The estimated density of uncompacted hulls is about 1 g/cm^3 , or about 15% of theoretical density (TD).⁽¹⁾ Melting would produce ingots with a density of 6.5 g/cm^3 , whereas flattening and compaction processes have been estimated to change the density to about 3.3 g/cm^3 (50% TD) for rolling and from 4.6 to 5.3 g/cm^3 (70 to 80% TD) for compaction. These figures are based on unirradiated hull material; no information on flattening or compaction has been developed concerning leached irradiated hulls taken to LWR exposure levels.

Assurance must be provided that the compacted hulls are in a safe stable condition, at least equal to that of the uncompacted hulls. Due to the anticipated brittle nature of irradiated Zircaloy hulls, any flattening or compaction operation may generate fines which are pyrophoric. If the hull surfaces were clean and free of oxides, the compact would bond together under sufficient pressure, thus encasing the fines except on the surface. This method is used commercially for recycling unirradiated Zircaloy-2 scrap.⁽⁷⁾ The scrap is pickled in a $\text{HNO}_3\text{-HF-H}_2\text{O}$ solution to produce an oxide-free surface prior to compacting. Then it is pressed into compacts 24 cm dia by 13 cm high (9.5 in. dia by 5 in. high) with about 72% TD, using a unit pressure of 52,500 psi. The leached and rinsed irradiated hulls most likely will not bond together with any standard compacting procedure, due to surface oxides and other corrosion residue. Demonstration tests must be performed with irradiated hulls to determine hull behavior under deformation before the suitability of a flattening or compaction process can be definitely determined.

To insure good results using either flattening or compaction, the fuel residue from the LWR fuel dissolution step must be sorted to provide a uniform solid-to-void ratio through the mix. The material from the chop-leach step can be sorted into three groups: 1) residue from the fuel rods (hulls, end caps, plenum springs, and spacer pellets), 2) other assembly

hardware (end fittings, support rods, tie plates, and casings), and 3) the fines generated in the processing step. It is assumed that the fines will not be processed by mechanical compaction and instead will be deactivated by controlled oxidation and packaged separately with the hardware parts. The grid spacers, generally made of thin-gage Inconel, could be compacted with the hulls. If roll flattening is used, the solid parts from the fuel rods (end caps, spacer pellets) must be removed to prevent roll damage caused by concentrated roll loading when these parts pass.

The fuel assembly hardware could be separated prior to rod chopping if a fuel disassembly operation similar to that designed for the General Electric Company's Midwest (MFRP) plant* were to be used. It had been planned there to disassemble the fuel elements and to saw or shear the rods individually.⁽⁸⁾ The West Valley (NFS) Plant approach was to remove the end fittings and casing and chop the fuel as a bundle.⁽⁸⁾ The Barnwell Plant (AGNS) approach includes plans to shear the entire fuel assembly (including end fittings and casing).⁽⁸⁾ The NFS method might not require sorting if the grid spacers would readily compact; but the AGNS approach would probably require sorting to remove the casing and end fitting material. For the concept described here it is assumed that sorting is required.

The feed material will be washed with nitric acid solution followed by a water rinse. However, this wash is not intended to decontaminate or remove the oxide coating,⁽⁹⁾ and it is doubtful that bonding will result during normal press compaction due to the oxide coating and the brittleness of the hulls. However, bonding of partially oxidized surfaces would probably occur if deformation under high pressure, as encountered during extrusion, was utilized.

4.2.2.1 Process Alternatives for Mechanical Compaction of Hulls

Options for mechanical volume reduction can be classified into these categories:

1. Compaction - hydraulic press
 - high-energy rate compaction
 - extrusion
 - swaging
2. Flattening - roll
 - press

None of the above options has been evaluated with irradiated hulls. Although no experience exists, it may be assumed that the deformation occurring in compaction or flattening will fracture the hulls because of the high oxygen and hydrogen content in zirconium, which makes the zirconium more brittle. This may create fines with fragments small enough to be pyrophoric. Any mechanical compaction process should provide containment for the compacted hulls. If compacting is done into an open container, the operation should be performed in an inert atmosphere. These guidelines would rule out roll flattening because the hulls would not be contained. Press flattening could be done in a container.

The hulls could probably be compacted to >80% TD by extrusion, but this operation would require that the hulls be vacuum sealed into billet-sized cans and heated prior to extrusion.

* This plant has been declared inoperable by GE and there are no current plans for using it.

Due to the 80 to 85% void space in the hulls, this method would require precompacting the hulls into the billet cans to at least 50% TD prior to extrusion. Even with precompaction to 50% TD, the extrusion may have a badly wrinkled clad with possible breaks or tears. The need for canning and precompaction, together with the high capital investment for extrusion and the difficulty in maintaining the equipment remotely, rules out this method as a feasible approach to compaction.

Compaction by swaging would require sealing the material in tubes. This method would also require a precanning operation, and the high void space would require several passes to compact. The end product would consist of a high ratio of canning tube to hulls; thus, this approach, like extrusion, does not appear feasible.

Press compaction is at present the most applicable compaction method and for that reason was selected as the reference concept. Press or high-energy rate compaction processes will also produce fines, some of which will show up at the surface of the compact. Compaction would need to be performed in an inert atmosphere, and any fines which are ejected from the container during compaction should be separated and then deactivated by oxidation.

4.2.2.2 Hulls Compaction Facility Design Basis

The hulls compaction facility (HCF) is an integral part of the 2000-MTHM reference FRP described in Section 3.2.3. The hulls are assumed to be separated from fuel assembly hardware and fines before compaction. The facility is designed for a throughput capacity of 2.6 m^3 (90 ft^3)/day of untreated fuel residue. About 84 canisters of hardware and deactivated fines and 198 canisters of compacted hulls are produced annually. Other criteria are the same as described in Section 4.2.1.2.

4.2.2.3 Mechanical Compaction Process

A flow diagram for processing fuel residue via mechanical compaction is shown in Figure 4.2.8. It is assumed that the hull material from the leach process will not bond together at reasonable compaction pressures. Therefore, it is desirable to reduce the pressure to a value which will only flatten the hulls and will decrease the volume to provide a theoretical density of about 50%. A compacting pressure suggested by Blomeke et al.⁽⁷⁾ would be in the range of 20,000 to 100,000 psi. Teledyne Wahchang Albany (TWCA) uses 52,500 psi in compacting Zircaloy scrap.⁽⁹⁾ Experiments conducted at Pacific Northwest Laboratory on chopped unirradiated tubing indicated that a 50% theoretical density (70% volume change) will require 12,000 psi while 20,000 psi will produce a theoretical density of 56% (73% volume change). Irradiation will increase the yield and tensile strength of hulls by about 30%;⁽⁸⁾ therefore, it is estimated that a 30% increase in compaction force will be required to compact irradiated hulls. Thus for a 50% TD the required force is expected to be about 16,000 psi. Compacting into a container 25 cm (10 in.) in diameter will require a 700-ton, vertical hydraulic ram press. The compaction can would need to be supported by a heavy containment die which would be removed after the can is filled. This approach is suggested by Seyfried⁽¹⁰⁾ for compacting general laboratory-type wastes.

4.2.21

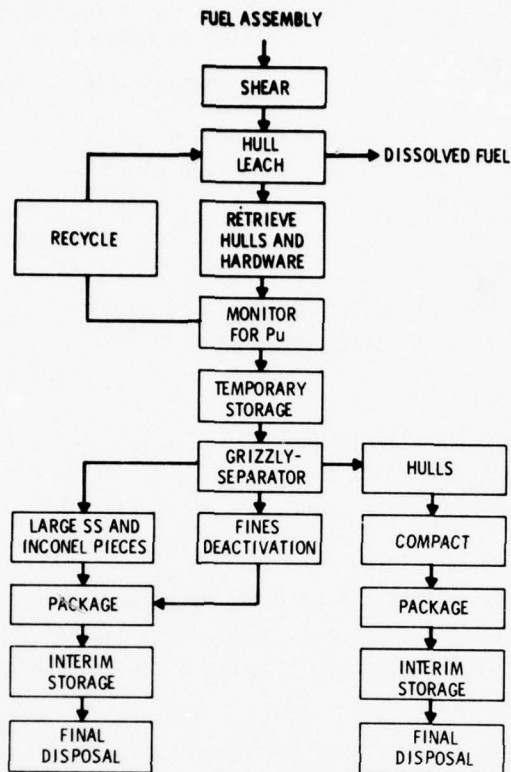


FIGURE 4.2.8. Flow Diagram for Mechanical Compaction of Hulls

In summary, the compaction process consists of segregating the sheared hulls from the stainless steel end fittings and other fuel element hardware and from the Zircaloy fines on a combination vibratory grizzly-separator, followed by compaction of the hulls in a hydraulic ram press. The compacted hulls are sealed into stainless steel containers, while the Zircaloy fines are deactivated by controlled oxidation to eliminate pyrophoric hazards, and are packaged with the end fitting components without the compaction step.

Table 4.2.1 shows the activity, volume, and density of the untreated fuel residue. Table 4.2.13 gives a description of fuel residue treated by mechanical compaction.

4.2.2.4 Hulls Compaction Facility Description

This section outlines the facility requirements for a hulls compaction facility (HCF). This facility receives the leached hull fuel residue remaining in the FRP dissolver after dissolution of the chopped fuel and reduces the residue volume by compaction, packages it in steel containers, and prepares it for storage or shipment to a repository.

General Description. The facility for the compaction of the fuel residue is centered around a remotely operated cell 7.9 m (26 ft) wide, 17.0 m (56 ft) long, and 10.4 m (34 ft) high. The facility is controlled and operated from the operating gallery behind 1.2 m (4 ft) concrete shielding walls provided with shielding windows and manipulators.

TABLE 4.2.13. Description of Fuel Residue Treated by Compaction

	<u>Cladding Hulls</u>	<u>Assembly Hardware</u>
Volume ^(a)	280 m ³ /yr	120 m ³ /yr
Density	1900 kg/m ³	970 kg/m ³
$\frac{\text{Volume treated}^{(a)}}{\text{Volume untreated}}$	0.52	1.04
Canister ^(b) /yr	198	84
Canister surface dose rate	>10 R/hr	>10 R/hr
Radioactivity as fraction of input ^(c)	1.0	1.0

a. Volume of waste canisters.

b. 75 cm dia x 3 m long.

c. See Table 4.2.1.

Because this facility is an integral part of the FRP, certain services and auxiliary systems required for its functioning, such as maintenance, utilities and so on, are part of the primary facility and are not described. Figures 4.2.9 through 4.2.12 show the layout and equipment arrangement required.

The HCF is located in the FRP and is a Category 1 structure. The hulls compaction cell is provided with a stainless steel pan that covers the floor and with radiation- and corrosion-resistant wall coatings. The decontamination station walls and floor, including the shielding door surfaces and the floor sumps, are lined with stainless steel.

Major Equipment. The systems and equipment required to perform the packaging function are described in the following paragraphs in operational sequence.

Stainless steel containers (Container "A" in Figure 4.2.9) with leached hulls arrive at the compaction cell on the powered roll conveyor. The 10-ton bridge crane lifts the containers and dumps the hulls onto the grizzly, where the large components are retained, the hulls and fines are passed to the separator below, and the fines are separated from the hulls. Grizzly motion is induced by an air vibrator applied to the frame that moves the material to the hulls canister located at the south side. Motion in the separator is produced by a vertically driven electric motor that has two eccentric weights rotating around the vertical axis. Centrifugal force of the rotating weights and their relative angle produce the required movement.

The separator sends the Zircaloy fines to the west side, into the fines deactivator, a unit that oxidizes zirconium by exposure to high temperature in the presence of air. The temperature in the deactivator is closely monitored to control the flow of air and inert gas that contact the fines. Air is metered to the deactivator only after the proper temperature is assured for slow oxidation of the fines. The deactivated fines are transferred to a conveyer and transported to the hulls canister to be mixed with the stainless hardware and, subsequently, to be sent to the welding station for capping and shipping.

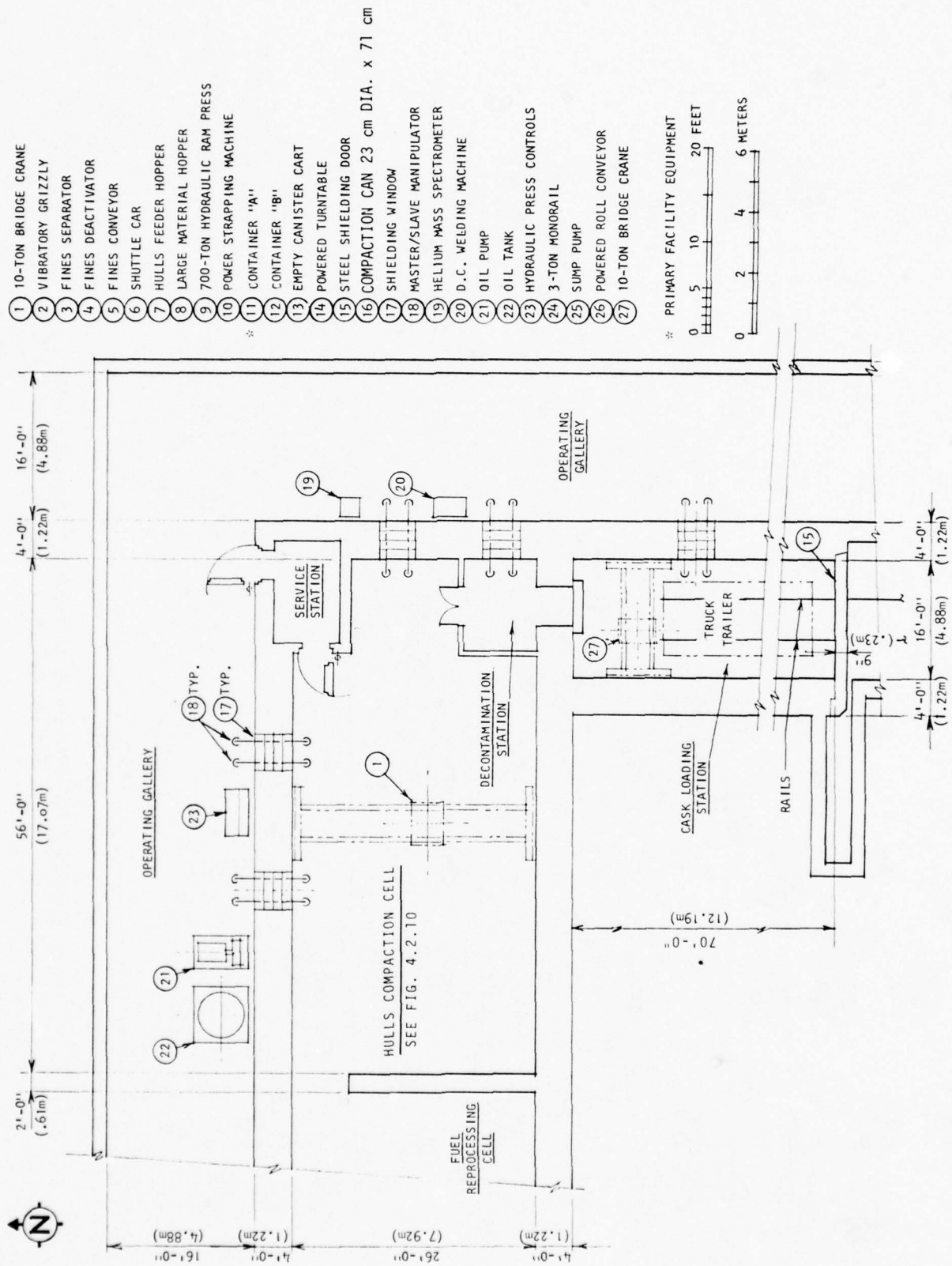


FIGURE 4.2.9. General Plan for Hulls Mechanical Compaction Process

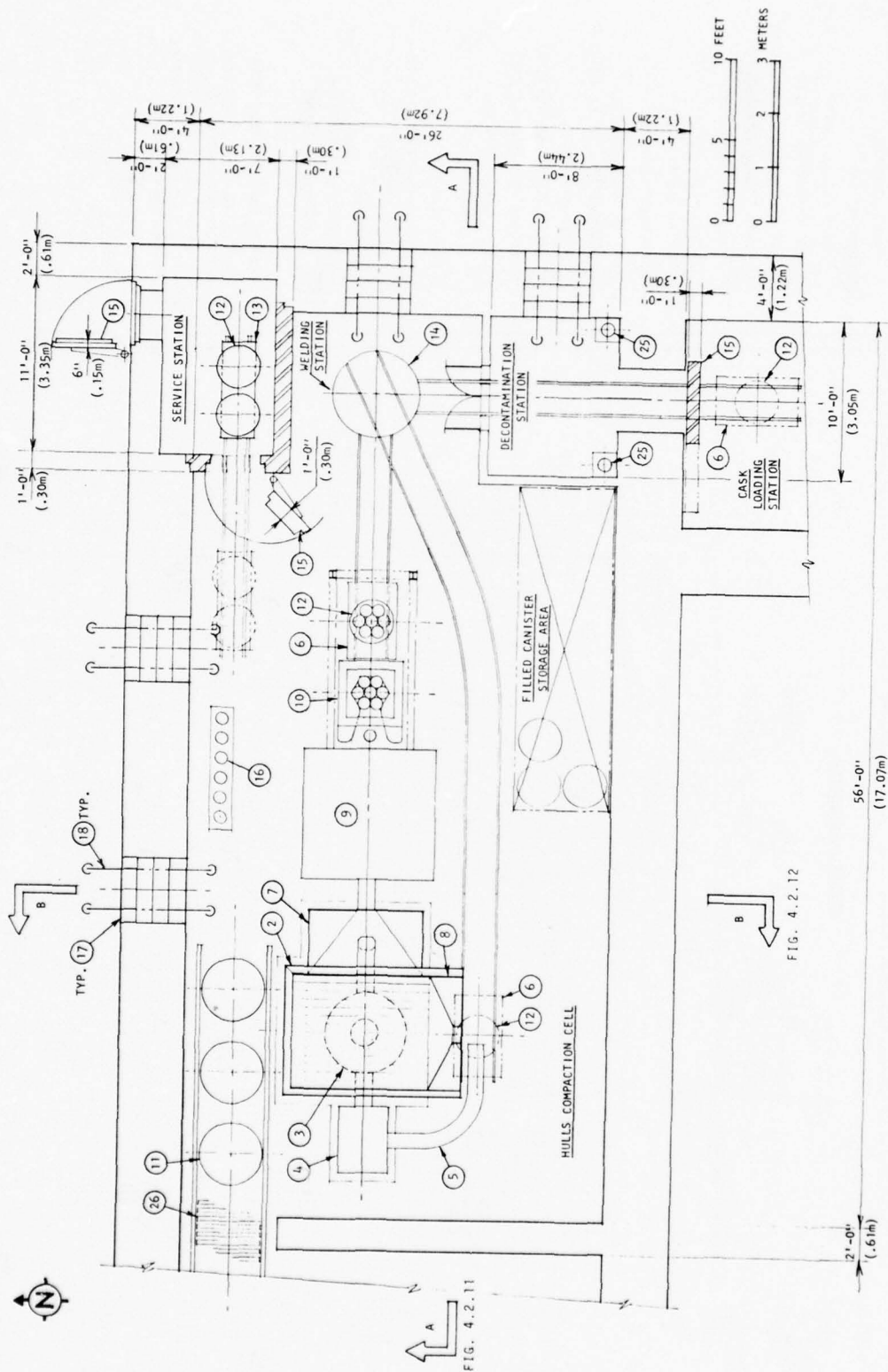


FIGURE 4.2.10. Plan for Hulls Mechanical Compaction Cell
(Circled numbers refer to key in Figure 4.2.9.)

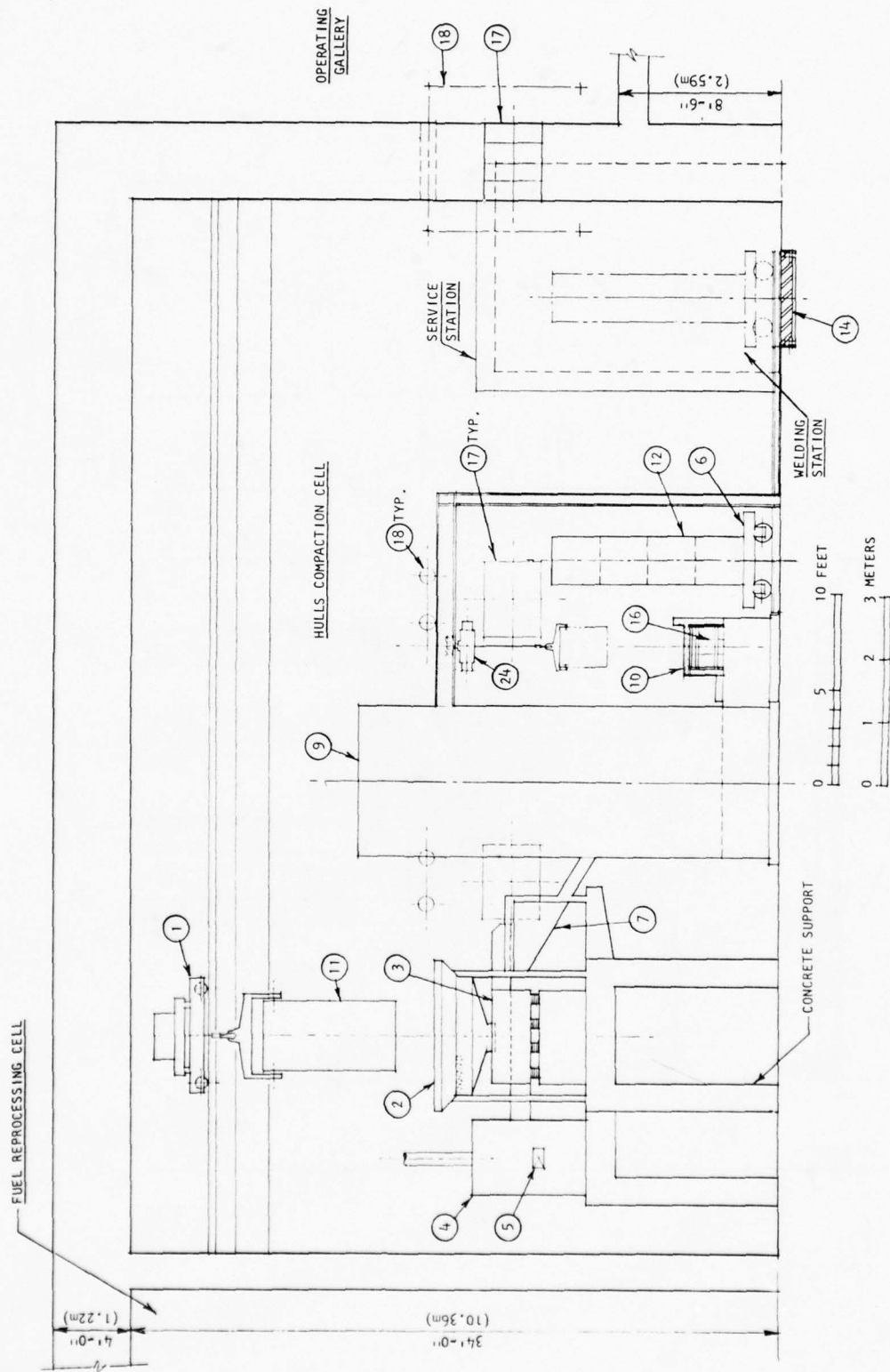


FIGURE 4.2.11. Hulls Mechanical Compaction Cell, Section A-A
(Circled numbers refer to key in Figure 4.2.9.)

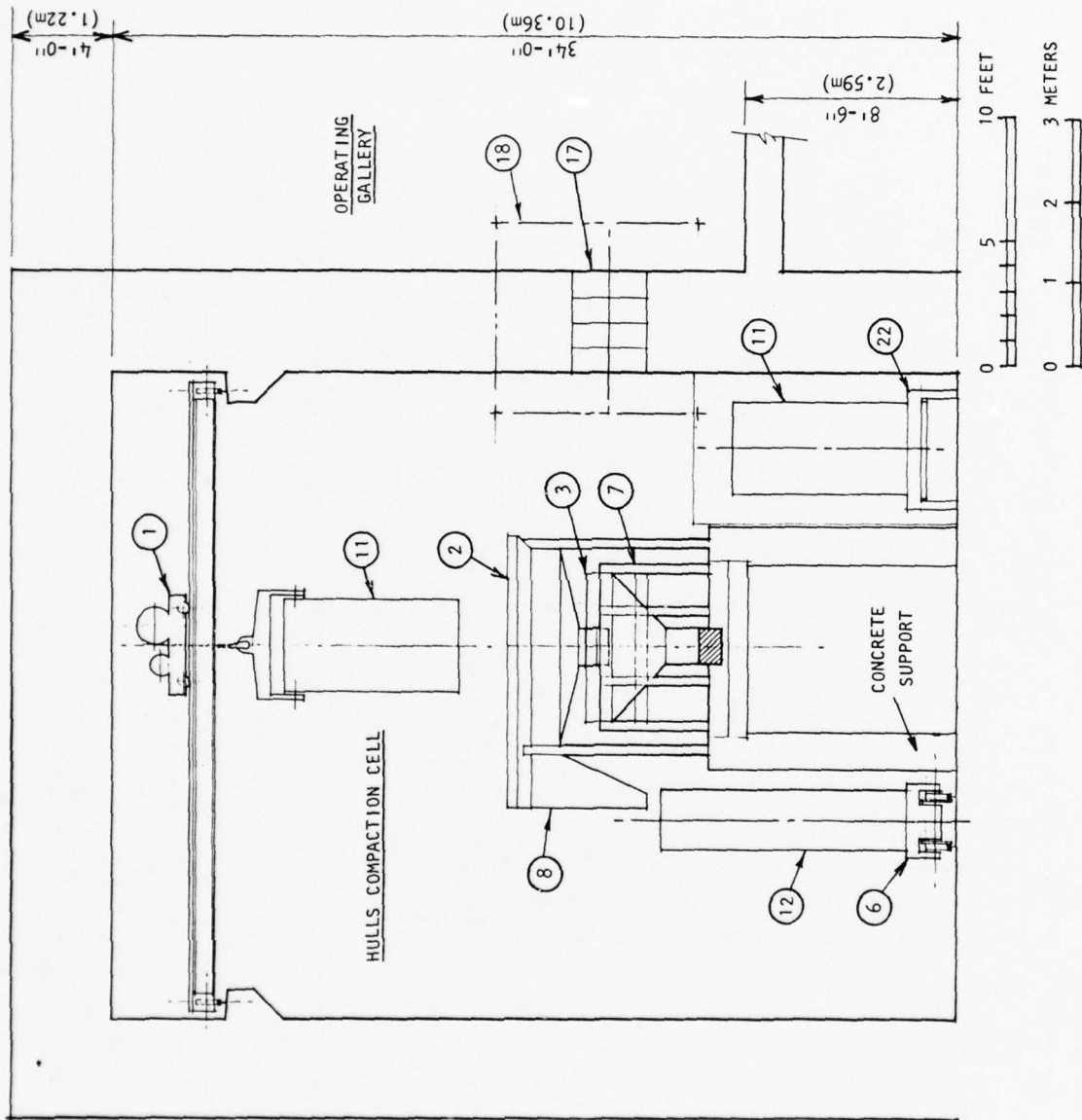


FIGURE 4.2.12. Hulls Mechanical Compaction Cell, Section B-B
(Circled numbers refer to key in Figure 4.2.9.)

4.2.27

The bulk of the waste (about 83 weight%) consists of Zircaloy cladding hulls that are vibrated to the east side into the hulls feeder hopper.

The hulls feeder has a stainless steel hopper capable of holding 1.27 m^3 (45 ft^3) of material, or the feed for one-half day of operations. The operation and release of material to the compaction can is coupled with the press so that about 6.25 kg (14 lb) of material is released before each stroke. Fifteen compaction strokes are required to complete one compact. Each compact is 0.23 m (9 in.) in diameter by 0.71 m (2 ft, 4 in.) long and weighs about 96.3 kg (212 lb).

The press is a self-contained hydraulic unit that has an oil-operated ram mounted on the frame. The compression is made inside the compaction can, which is firmly supported by a strong cylindrical die that is removed when the work is completed. The compact is ejected from the press area into the strapping machine where seven compacts are accumulated before the machine is activated and a bundle formed.

Twenty-eight compacts, or four bundles of seven units, are loaded into the hulls canister, Figure 4.2.7, (Container "B" in Figure 4.2.9) by the monorail installed in the overhead steel structure. The canister is mounted on the shuttle car, a remotely operated vehicle that rides on steel tracks, between the hulls loading, the welding, and the cask loading stations. After packaging is completed, the shuttle car is moved to the welding station.

The welding station, located at the east side of the cell, consists of a power turntable where the shuttle car is secured and an overhead support frame to hold the electrode rod, argon supply line, helium test probe, and a stack of container lids. The work is rotated while the welding and the leak testing equipment above remain stationary.

The welding process is the automatic gas-tungsten arc with no filler metal. Only one pass will be required to complete the weld and start the helium test.

When the container is brought into the shipping area, it will be tested and inspected for contamination. Here, if needed, decontamination solution will be sprayed on all sides to remove the contamination and reduce the potential of contaminating the cask and the interim storage facility. The clean container is transferred to the cask loading station, where a hulls cask has been introduced. Loading into the cask and handling of the sealed canister is done remotely from the operating station, but all other routine operations are done by direct contact inside the cask loading station with the shielding door to the compaction cell closed.

Shielding and Remote Handling Equipment. The compaction equipment is located within the operating canyon; therefore, the shielding provided is more than adequate. Manipulator through-tubes and similar equipment will require shielding equivalent to 25 cm (10 in.) of lead.

4.2.2.5 Hulls Compaction Facility Operating and Maintenance Requirements

It is estimated that the press throughput would be about 3 compacts/hr or 24 compacts/8-hr shift. About 22 compacts (100 kg each) per day 5 days per week are required to meet throughput requirements. Assuming a plant factor of about 50%, the plant would require a two-shift, 5-day week operation. For this analysis a single press operation is assumed, although redundancy of presses and sealing station might prove to be desirable in providing continuous operation of the plant.

4.2.28

Experience is not now available regarding the remote operation and maintenance of a ram press. The design must permit routine remote maintenance operations. No unusual maintenance procedures are expected.

Staffing. Staffing requirements are given in Table 4.2.14.

TABLE 4.2.14. Staffing Requirements for the Hulls Compaction Facility

<u>Job Description</u>	<u>Personnel Required, man-yr/yr</u>
Operators	13
Radiation monitors	1
Maintenance craftsmen	3

Supplies and Utilities. Utilities and supplies required for this task are shown in Table 4.2.15.

TABLE 4.2.15. Supply and Utility Requirements for the Hulls Compaction Facility

<u>Item</u>	<u>Use Rate</u>	<u>Annual Requirement</u>
Electricity	100 kW	312,000 kWh
Water consumed	3 kg/min	5.9×10^5 kg
Argon	200 l/min	$40,000 \text{ m}^3$
Helium	20 l/min	$4,000 \text{ m}^3$
Hydraulic oil	8 l/day	100 l
Canisters	2/day	282

Hazardous Materials. Some quantity of Zircaloy fines will be produced during sorting and compaction and must be treated as a hazardous (pyrophoric) material. The hazards associated with Zircaloy fines are discussed in Section 4.2.1.9.

4.2.2.6 Hulls Compaction Facility Secondary Radioactive Wastes

Table 4.2.16 lists the secondary wastes associated with the compacting operation.

TABLE 4.2.16. Secondary Radioactive Wastes from the Mechanical Compaction of Hulls

<u>Description</u>	<u>Volume, m^3/yr</u>	<u>Radioactivity Factor^(a)</u>
Combustible and compactable waste	60	1.1×10^{-6}
Wet waste	1	1.1×10^{-4}
Failed equipment	6	1.1×10^{-4}

a. Fraction of input activity (Table 4.2.1) in secondary wastes.

4.2.2.7 Hulls Compaction Facility Emissions

Estimated emissions are given in Table 4.2.17. An estimate of the integrated annual release due to minor accidents (Section 4.2.2.9) for this facility is also included in Table 4.2.17. It was developed by weighing the minor accident releases by their expected frequencies and summing the quantities for all identified minor accidents. In addition, a contingency was included in the integrated release to account for unidentified minor accidents and to compensate for the uncertainty in expected frequency information.

TABLE 4.2.17. Hulls Compaction Facility Emissions

Emission	Description	Annual Quantity	Radioactivity Reduce Factor ^(a) to Atmosphere	
Gaseous	Cell ventilation air	$3 \times 10^8 \text{ m}^3$	All	1×10^{-13}
	Minor accident integrated annual release		^3H	4×10^{-6}
			All others	4×10^{-13}
Cooling tower water:	• evaporated, $T = 38^\circ\text{C}$	$5.0 \times 10^5 \text{ kg}$		
	• drift, $T = 38^\circ\text{C}$	$2.4 \times 10^3 \text{ kg}$		
	• blowdown, $T = 27^\circ\text{C}$	$8.6 \times 10^4 \text{ kg}$		
Other	Heat	$3.4 \times 10^2 \text{ MW-hr}$		
		$(1.1 \times 10^9 \text{ BTU})$		

a. Fraction of input activity (Table 4.2.1). Includes a DF of 10^4 for particulates in plant APS. Released over 250 days/yr.

4.2.2.8 Hulls Compaction Facility Decommissioning Considerations

The life of the compaction facility is expected to be equal to the life of the reprocessing facility. For final disposal purposes, the equipment would be treated as TRU-contaminated waste.

4.2.2.9 Hulls Compaction Facility Postulated Accidents

Hulls processing by mechanical compaction requires separation of fines (and hardware) from the hulls in a grizzly-separator. The fines are isolated and deactivated prior to packaging; however, an accumulation of up to 10 kg of fines in the grizzly is possible. This accident scenario is described in Table 4.2.18. No accidents that could be classified as moderate or severe accidents could be realistically postulated for this technology. The pyrophoricity of zirconium and the criticality safety considerations were discussed in Section 4.2.1.9. The allowable concentration of undissolved fuel that may remain with the compacted cladding hulls without exceeding the critical masses given in Section 4.2.1.9 is given for different fuel enrichments in Table 4.2.19.

For purposes of environmental consequence analysis, the release from a zirconium fines fire (accident 4.2.2) was selected as an umbrella source term (see Section 3.7-Basis for Accident

TABLE 4.2.18. Hulls Compaction Facility Minor Accidents

Accident No. and Description	Sequence of Events	Safety Systems	Release
4.2.2-Zr fines fire. Estimated frequency ~0.1/yr	<ol style="list-style-type: none"> 1. Fines accumulate in grizzly. 2. A spark, or heat source ignites the fines. 3. Fire releases volatile activity. 	<ol style="list-style-type: none"> 1. Grizzly designed to prevent fines accumulation. 2. Deactivation of separated fines. 3. Predrying of hulls and fines. 	<p>10 kg Zr fines burn, releasing to the cell atmosphere in 0.5 hour:</p> <ul style="list-style-type: none"> • 33 kWh heat energy • A radionuclide inventory based on the amount of Zr available from reprocessing 37.6 kg of heavy metal. ³H would remain gaseous while Cs, Te, Ru and Rb are expected to act as particles. All others would either not volatilize or would plate out before reaching the facility filters.

TABLE 4.2.19. Allowable Percent Undissolved Fuel in a Canister of Compacted Hulls

Fuel Enrichment	Allowable % Undissolved Fuel
4% ²³⁵ U	0.49
5% ²³⁵ U	0.31
4% Pu	0.35
5% Pu	0.26

(Analysis). This means that releases from accident 4.2.2 are the largest amounts of activity in its release group from accidents in the waste management system. Source term categories are cross-indexed by accident number in Appendix A of Section 3. Releases from accident 4.2.2 are based on an assumed accumulation of 10 kg of fines in the grizzly separator before ignition. This is believed to be a conservative upper limit for this type of equipment. A loss of inert cover gas and an ignition source must also be postulated for combustion to occur. Ignition is postulated to occur from sparking of hulls during the separation process. During combustion many nuclides would be vaporized. It is expected that only the most volatile would reach the facility exhaust filters before settling out on surfaces in the cell. Some damage to the grizzly separator is expected due to vigorous local heating. Replacement of this equipment may be necessary.

4.2.2.10 Hulls Compaction Facility Costs

Estimates of capital, operating, and levelized unit costs are presented in mid-year 1976 dollars. A complete description of the cost estimate bases, assumptions, and definitions is given in Section 3.8.

Capital Costs. The capital cost estimate for the HCF is shown in Table 4.2.20, expressed in mid-year 1976 dollars. The estimate covers all capital costs specifically resulting from inclusion of the HCF as an integral part of the FRP described in Section 3.2.3. These costs also include the effect of incremental additions to utility supplies, such as electrical substation, HVAC, compressed air, and similar auxiliaries, as well as the cable, piping and other bulk materials incorporated directly into the HCF. However, general FRP costs for such services as laboratories and warehousing are not allocated.

TABLE 4.2.20. Capital Cost Estimate for Hulls Compaction Facility

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		18	2,300	200	2,500
Buildings and structures		125	920	1,530	2,450
Bulk materials		96	1,900	1,200	3,100
Site improvements		1	20	10	30
Subtotal of direct site construction costs		240	5,140	2,940	8,080
Indirect site construction costs	65	44	1,090	1,420	2,510
Total field cost	65	284	6,230	4,360	10,590
Architect-engineer services					2,100
Subtotal					12,690
Owner's cost					4,210
Total facility cost					16,900
Estimate accuracy range					±30%

The total capital cost includes all plant-related costs incurred from the start of engineering to the start of commercial operation, excluding only working capital.

Operating Cost. The reference facility's annual operating cost is shown in Table 4.2.21. Direct labor costs are based on requirements in Table 4.2.14. Process materials costs are based on requirements shown in Table 4.2.15. The compaction canisters cost about \$8000 each in lots of 100 or more. Utility cost estimates are based on requirements also shown in Table 4.2.15. Annual maintenance materials costs are estimated at 3% of the initial equipment investment. Overhead, maintenance, and miscellaneous costs are based on factors given in Section 3.8. The estimates for the miscellaneous items are assumed to include all unidentified operating costs. The costs of taxes, insurance, and interest, however, are included in the capital segment of the levelized unit cost.

TABLE 4.2.21. Operating Cost Estimate for Hulls Compaction Facility

Cost Element	Annual Costs, \$1000s
Direct labor	420
Process materials	2330
Utilities	10
Maintenance materials	80
Overhead	510
Miscellaneous	50
Total	3400 ±25%

4.2.32

Levelized Unit Cost. The levelized unit cost, including the levelized capital and operating segments, is shown in Table 4.2.22. The unit cost calculation assumes private ownership of the facilities and a 15-yr economic life. Separate costs are shown for facilities shipping the canisters by truck or by rail since a special shipping facility costing \$900,000 would be required to handle rail casks. The operating costs for a rail or truck facility are not significantly different.

TABLE 4.2.22. Levelized Unit Cost Estimate for Hulls
Compaction Facility

Cost Element	Unit Cost, \$/kg HM	
	Truck Shipment	Rail Shipment
Levelized capital charge	2.10	2.20
Levelized operating charge	<u>1.70</u>	<u>1.70</u>
Levelized total unit cost	3.80 ±30%	3.90 ±30%

4.2.2.11 Hulls Compaction Facility Construction Requirements

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information which follows provides a basis for evaluating the impact of construction activities.

Project Schedules and Construction Manpower. The schedule for engineering, procurement, and construction of the HCF is an integral factor in the overall schedule for the FRP. This schedule is given in Section 3.2.3.7. The field labor force estimated for the construction phase of the HCF is tabulated below:

	Man-hours, 1000s
Manual field labor	284
Nonmanual field labor	<u>65</u>
Total field labor	349

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials, and services provided at the site of the FRP, while offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is as shown below:

	Costs, \$1000s
Onsite	4,400
Offsite	<u>12,500</u>
Total	16,900

Site Requirements. This facility will share the same site as the FRP. No additional site requirements beyond those for the FRP are identifiable. Land commitments are included with those of the FRP.

Water. About 4200 m^3 (1.1×10^6 gal) of water are required during the construction period.

Construction Materials. Construction materials committed to the HCF are:

Concrete	$2,300 \text{ m}^3$	(3,000 yd^3)
Steel	630 MT	(690 tons)
Copper	5.5 MT	(6 tons)
Zinc	0.5 MT	(0.5 tons)
Lumber	140 m^3	(60 MFBM)

Energy. Energy resources used during construction will be:

Propane	42 m^3	(11,000 gal)
Diesel Fuel	420 m^3	(110,000 gal)
Gasoline	290 m^3	(76,000 gal)
Electricity:		
Peak demand	320 kW	
Total consumption	210,000 kWh	

Transportation Requirements. No separately defined transportation requirements for the HCF have been identified beyond those for the FRP.

4.2.2.12 Effects of Fuel Cycle Options

See Section 4.2.1.12.

4.2.3 Hulls Melting Process

Further reduction in the volume of hulls for disposal is possible by melting the hulls into compact ingots. The chemical reactivity of zirconium at its melting point ($\sim 1850^\circ\text{C}$) requires that it be melted in vacuum or in an inert atmosphere. Conventional crucible materials react vigorously with molten zirconium. Graphite crucibles exhibit fair resistance to molten zirconium. However, crucible life is short, and each crucible used would contribute to the waste volume.

4.2.3.1 Hulls Melting Process Alternatives

Cold crucible processes have been developed for producing zirconium;⁽¹¹⁾ these processes have also been used for remelting iron, nickel, and cobalt alloys. Alternative cold crucible melting techniques have been evaluated for densification of fuel residue.⁽¹²⁾ Conclusions from this evaluation resulted in selecting the Inductoslag process as the most promising process for this application.

4.2.3.2 Hulls Melting Facility Design Basis

The design criteria for hulls melting are identical to those in Section 4.2.2.2, with the exception that the separated hulls are compacted by melting instead of mechanical densification. The facility will produce six Zircaloy ingots per day. Each ingot is 23 cm (9 in.) diameter by 145 cm (4 ft 9 in.) long. In one year, 109 canisters of ingots and 84 canisters of hardware and Zircaloy fines will be produced.

4.2.3.3. Hulls Melting Process

The Inductoslag melting process, developed by Clites and Beall^(13,14) of the United States Bureau of Mines in Albany, Oregon, uses induction heating. The melt is insulated from a split, water-cooled crucible by a layer of frozen slag. Melting takes place in static, 1/3-atm pressure helium or argon.

The bulk density of the cladding hulls is insufficient to give coupling to the induction coils and thus achieve melting. The Inductoslag melting process is, therefore, initiated with pieces of mild steel to establish a molten "starting stub." About 48 kg (106 lb) of scrap mild steel is added to the melter on a water-cooled copper base along with the CaF_2 flux. The scrap steel is sized to give a bulk density in the melter that will give coupling to the induction coils. Once melting is initiated, hulls can be added to the molten pool, which soon becomes a molten pool of Zircaloy. The starting configuration for the Inductoslag melter is shown in Figure 4.2.13; Figure 4.2.14 shows the principles of its operation for the running mode.

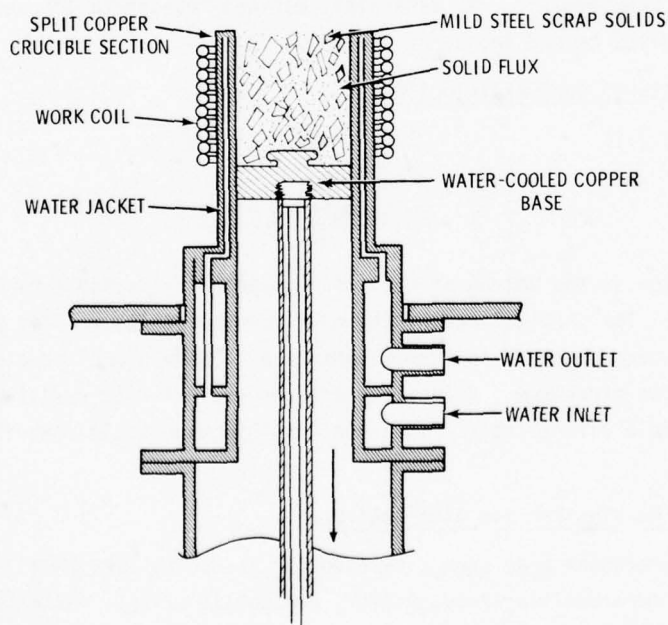


FIGURE 4.2.13. Inductoslag Melting Process Starting Configuration

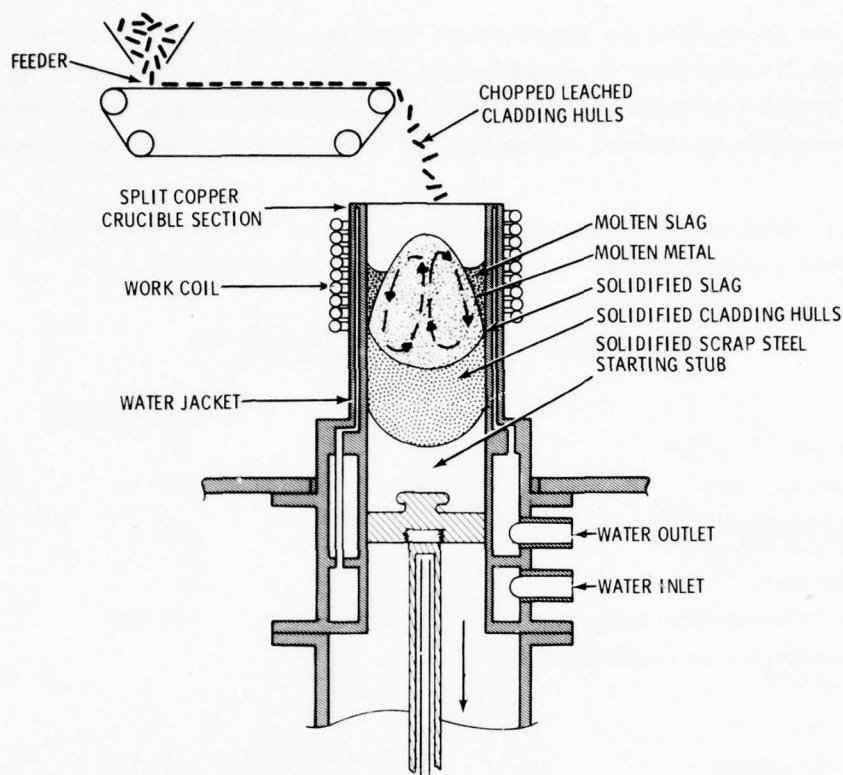


FIGURE 4.2.14. Inductoslag Melting Process Running Configuration

The furnace is cooled and the 23 cm (9 in.) diameter ingot removed after a length of 1.45 m (4 ft 9 in.) has been reached. The water-cooled copper base is designed with a tapered notch to allow its removal from the ingot starting stub and its reuse. The ingot, which includes the starting stub weight of 48 kg (106 lb), is cleaned and packaged in hulls canisters (14 ingots/canister) for shipment to interim storage or a repository.

This process has been successfully demonstrated for making ingots 10 cm (4 in.) in diameter of Zircaloy, stainless steel, and Inconel using unirradiated simulated fuel residues.⁽¹⁵⁾ Mixtures of Zircaloy with about 10 to 15% stainless steel and Inconel do not melt fast enough, using the Inductoslag process, to make production scale-up forecasts for these mixtures at this time. Therefore, the proposed process requires separating Zircaloy hulls and hardware. The stainless steel end fittings and spacers could be melted separately in the same melting furnaces after segregation if a size reduction operation was added to the proposed plant. However, this approach is not considered. It is assumed that the end fittings and spacers will be packaged separately without treatment. The proposed plant is believed to be a reasonable scale-up from ingots 10 cm (4 in.) in diameter by 90 cm (3 ft) long to ingots 23 cm (9 in.) in diameter by 145 cm (4.75 ft) long.

The flowsheet for melting is identical to that shown in Figure 4.2.8 except that the facility uses the Inductoslag melting process instead of compacting. Prior to melting, the sheared

cladding hulls are segregated from the stainless steel end fittings and other fuel element hardware and from the Zircaloy fines on a combination vibratory grizzly-separator. The ingots from the melter are sealed into stainless steel containers while the Zircaloy fines are deactivated to eliminate pyrophoric hazards and are packaged with the stainless steel components without the melting step.

Table 4.2.1 Shows the activity, volume, and density of the untreated fuel residue; Table 4.2.23 gives a description of fuel residue treated by hulls melting.

TABLE 4.2.23. Description of Fuel Residue
Treated by Hulls Melting

	Cladding Hulls	Assembly Hardware
Volume, (a) m ³ /yr	150	120
Density, kg/m ³	3500	970
$\frac{\text{Volume treated (a)}}{\text{Volume untreated}}$	0.28	1.04
Canisters (b)/yr	109	84
Canister surface dose rate	>10 R/hr	>10 R/hr
Radioactivity as fraction of input(c)		
³ H	0	
All others	1.0	1.0

a. Volume of waste canisters.

b. 75 cm dia x 3 m long.

c. See Table 4.2.1.

4.2.3.4 Hulls Melting Facility Description

This section describes the reference hulls melting facility (HMF). The HMF is designed to be an integral part of the fuel reprocessing plant (FRP) described in Section 3.2.3. The purpose of this facility is to receive the leached hull fuel residue remaining in the FRP dissolver after dissolution of the chopped fuel and to reduce the volume of residue by furnace melting into ingots, packaging the ingots in steel containers, and preparing the containers for interim storage or shipment to a repository.

General Description. The facility for the melting process is centered around a remotely operated cell 7.3 m (24 ft) wide, 16.5 m (54 ft) long, and 10.4 m (34 ft) high. The facility is controlled and operated from the operating gallery behind 1.2-m (4 ft) concrete shielding walls, provided with shielding windows and manipulators.

Because this facility is an integral part of the FRP, certain services and auxiliary systems required for its functioning, such as maintenance, utilities, etc., are part of the primary facility and are not described. The arrangement drawings which serve as the basis for the estimate are shown in Figures 4.2.15 through 4.2.17.

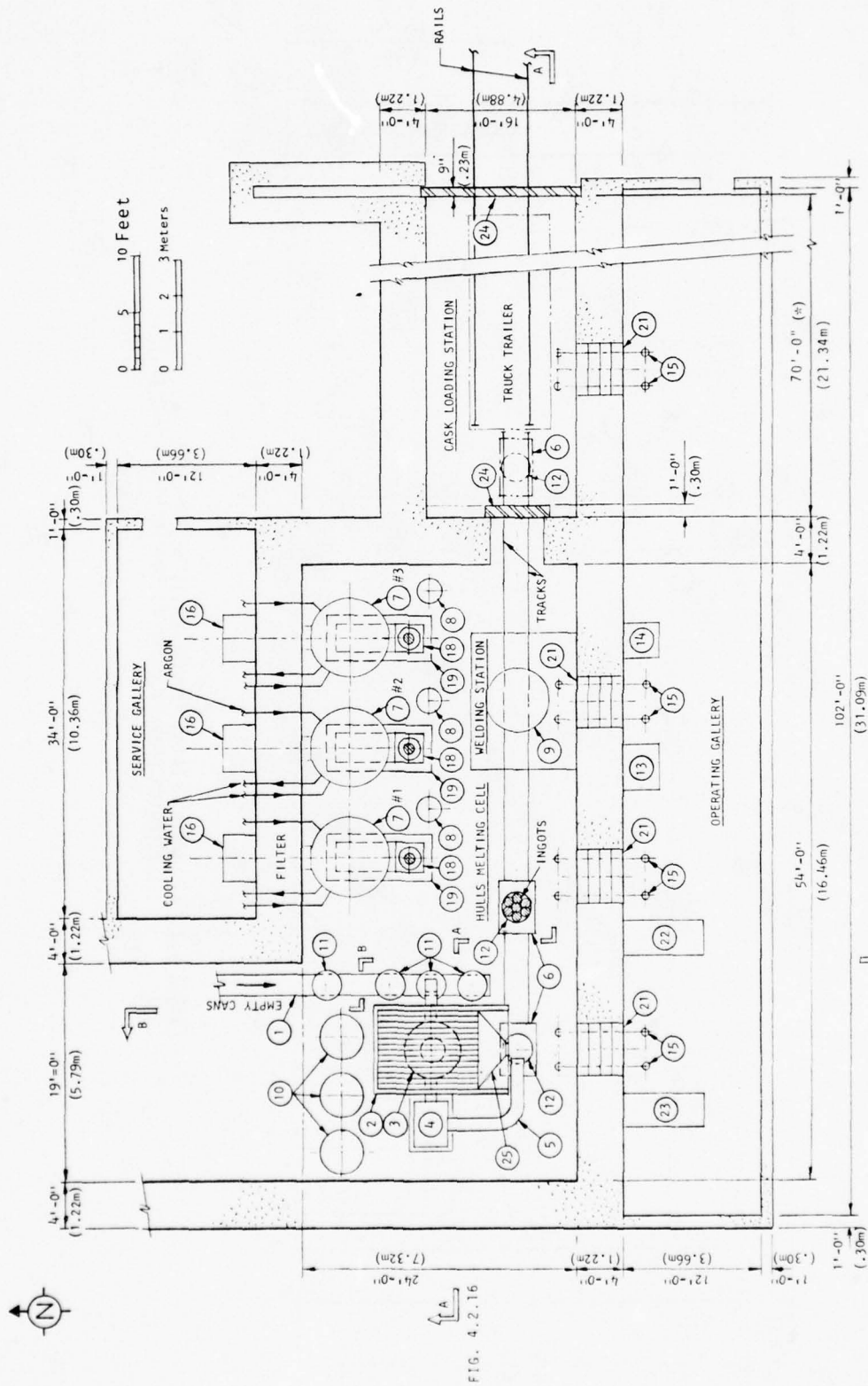


FIGURE 4.2.15. Hulls Melting Facility Plan
(Circled numbers refer to key in Figure 4.2.17.)

FIGURE 4.2.16. Hulls Melting Process Cell, Section A-A (Circled numbers refer to key in Figure 4.2.17.)

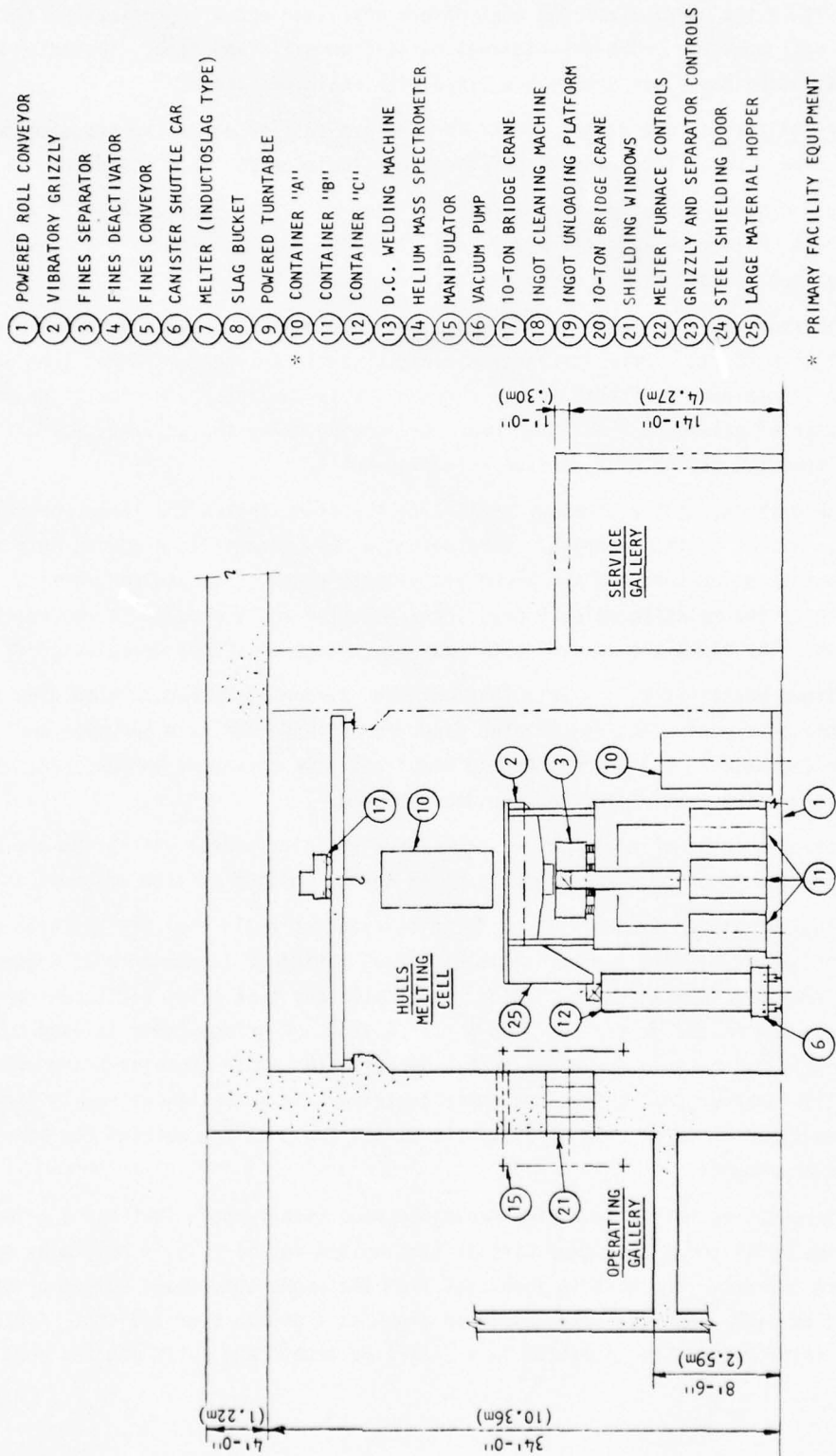


FIGURE 4.2.17. Hulls Melting Process Cell, Section B-B

The HMF is located in the FRP and is a Category 1 structure. The hulls melting cell is provided with a stainless steel pan that covers the floor and with radiation- and corrosion-resistant wall coatings. The decontamination station walls and floor, including the shielding door surfaces and the floor sumps, are lined with stainless steel.

Major Equipment. Operations within the HMF are carried on in the sequence described in the following paragraphs. Equipment descriptions are included for each operation.

Stainless steel containers (container "A" Figures 4.2.15 through 4.2.17) with leached hulls arrive at the melting cell from the adjacent dissolver cell carried by a bridge crane or other conveyance that is part of the dissolver cell equipment.

The 10-ton bridge crane lifts the containers and dumps the hulls on a grizzly 2.14 m (7 ft) x 2.44 m (8 ft). Here the large stainless steel components are retained and vibrated to a canister (container "C" Figure 4.2.15 through 4.2.17) on the south side. The remainder of the charged material passes to the fines separator located below the grizzly, where the fines are separated from the medium-size Zircaloy cladding hulls.

On the grizzly, an air vibrator applied to the frame shakes the large components toward the container. Motion on the separator, located below the grizzly, is produced by a vertically driven electric motor that has two eccentric weights rotating around the vertical axis. Centrifugal force of the rotating weights plus their relative angle produce the movement required for segregation. The fines are driven to the outside, where the fines deactivator is located.

The fines deactivator is a unit that oxidizes zirconium by exposure to high temperature in the presence of oxygen. The deactivated fines are transferred to a conveyor and transported to a canister (container "C") where they are mixed with the stainless hardware and, subsequently, sent to the welding station for capping and shipping.

The product canister that receives the large stainless steel pieces and the deactivated fines is mounted on a shuttle car and is moved to the welding station after it is filled.

The bulk of the waste consists of Zircaloy cladding hulls that are vibrated toward the east side of the separator into another stainless steel container (container "B" Figure 4.2.17) that is 0.76 m (30 in.) in diameter by 0.91 m (3 ft) high and that holds sufficient material to produce an ingot in the melter, or 0.35 m^3 (12.4 ft^3). A bridge crane is used to remove the filled containers and dump the hulls into a melter. The empty containers are returned to a powered roll conveyor that brings the empty containers in a continuous supply line to the filling position. A surge area is available at the front of the melters for storing filled containers and ingots.

The Inductoslag melter is a high-frequency induction furnace that has a primary circuit (the furnace coil) and a secondary circuit (the molten metal) that is heated by applying an alternating current. The melt is insulated from the segmented, water-cooled crucible by a layer of solidified slag. Melting takes place in argon at a pressure of 1/3 atm. A pool of scrap metal and calcium fluoride is melted in a "starting stub," and hulls are fed into the top of the

crucible as the ingot is removed from the bottom. Calcium fluoride in the amount of 3 wt% of the metal is required, but about 80% can be recycled and recharged to the furnace. Three furnaces are required.

Ingots are removed from the furnace, separated from the water-cooled copper base, and deposited in a bucket that is part of the slag-cleaning machine. The ingot is cleaned by an air vibrator applied to the ingot inside a bucket. This causes the slag to separate for later recycling.

Clean ingots are picked up by the bridge crane and loaded into a hulls canister (Figure 4.2.7, also container "C" in Figures 4.2.15 through 4.2.17).

Fourteen ingots, each weighing 390 kg (860 lb), are loaded in each hulls canister; each ingot is 0.23 m (9 in.) in diameter x 1.4 m (4 ft 9 in.). The canister is located in a canister loading area where, after being filled with ingots, it is moved to the shuttle car for transfer to the welding station.

The shuttle car is a remotely operated vehicle that rides on steel rails and travels to the welding station and cask loading station. Controls for the shuttle car are located at the operating gallery.

The welding station, located at the east side of the cell, consists of a power turntable where the shuttle car is secured and an overhead support frame to hold the electrode rod, argon supply line, helium test probe, and a stack of container lids. The work is rotated while the welding and the leak testing equipment above remains stationary.

The welding process is the automatic gas-tungsten arc with no filler metal since the inert gas envelope surrounding the tungsten electrode permits welding without flux. Only one pass is required to complete the weld and start the helium leak test.

When the container is brought into the shipping area, it will be tested and inspected for contamination. Here, if needed, decontamination solution will be sprayed on all sides to remove contamination and reduce the potential of contaminating the cask and the interim storage facility. The clean canister is transferred to the cask loading station, where a cask has been introduced. The canister of ingots is handled remotely and loaded into the cask from the operating station, but all other subsequent routine operations are done by direct contact inside the cask loading station with the shielding door to the melting cell closed.

Shielding and Remote Handling Equipment. The melting equipment would be located within the operating canyon; therefore, the shielding provided is more than adequate. Manipulator through-tubes and similar equipment would require shielding equivalent to 25 cm (10 in.) of lead.

4.2.3.5 Hulls Melting Facility Operating and Maintenance Requirements

Except when down for major maintenance, each of the three melters will operate in the melting mode about half the time. A typical one day's schedule for the melt shop is given in Table 4.2.24. Three shifts/day, 5 days/week will be required. Melter startup is described in Section 4.2.3.3.

TABLE 4.2.24. Furnace Melting Schedule

Furnace Number	Time, hr			
	0-6	6-12	12-18	18-24
1	Power on	Cool recharge	Power on	Cool recharge
2	Cool recharge	Power on	Cool recharge	Power on
3	Power on	Cool recharge	Power on	Cool recharge

Unusual Maintenance Requirements. Inductoslag melters have not, to date, been operated under remote operation and maintenance conditions. Periodic removal of pyrophoric deposits from the melter containment system may prove to be the most difficult maintenance problem. No further unusual maintenance needs are expected.

Staffing. Personnel requirements for operation of the hulls melting facility are given in Table 4.2.25.

TABLE 4.2.25. Staffing Requirements for the Hulls Melting Facility

Job Description	Personnel Required, man-yr/yr
Operators	15
Radiation monitors	1
Maintenance craftsmen	3

Supplies and Utilities. These requirements are given in Table 4.2.26.

TABLE 4.2.26. Supply and Utility Requirements for the Hulls Melting Facility

Item	Use Rate	Annual Requirement
Electricity	500 kW	3×10^6 kWh
Water consumed	15 kg/min	4.8×10^6 kg
Argon	30 l/min	$10,000 \text{ m}^3$
Helium	10 l/min	$3,000 \text{ m}^3$
Calcium fluoride	15 kg/day	3,200 kg
Steel for starting stub	300 kg/day	73 MT
Canisters	1/day	193

Hazardous Materials. Molten zirconium metal and water in close proximity present a potentially hazardous combination. Molten metal-water reactions are discussed in Section 4.2.3.9.

4.2.3.6 Hulls Melting Facility Secondary Radioactive Wastes

Secondary wastes from the hulls melting facility are listed in Table 4.2.27.

TABLE 4.2.27. Secondary Radioactive Wastes from the Hulls Melting Facility

Description	Volume, m ³ /yr	Radioactivity Factor ^(a)
Combustible and compactable waste	60	All 1×10^{-6}
Wet waste	1	All 1×10^{-4}
Failed equipment	0.6	All 1×10^{-4}

a. Fraction of input activity (Table 4.2.1) in secondary wastes.

4.2.3.7 Hulls Melting Facility Emissions

Estimated emissions are given in Table 4.2.28. An estimate of the integrated annual release due to minor accidents (Section 4.2.3.9) for this facility is included in Table 4.2.28. It was developed by weighing the minor accident releases by their expected frequencies and summing the quantities for all identified minor accidents. In addition, a contingency was included in the integrated release to account for unidentified minor accidents and to compensate for the uncertainty in expected frequency information.

TABLE 4.2.28. Emissions from Hulls Melting Facility

Emission	Description	Annual Quantity	Radioactivity Reduce Factor ^(a) to Atmosphere
Gaseous	Cell ventilation air	3×10^8 m ³	³ H 1.0 All others 1×10^{-13}
	Minor accident integrated annual release		³ H 4×10^{-6} All others 4×10^{-13}
Cooling tower water:	• evaporated, T = 38°C	4.1×10^6 kg	
	• drift, T = 38°C	2.0×10^4 kg	
	• blowdown, T = 27°C	7.2×10^5 kg	
Other	Heat	2.8×10^3 MW-hr (1×10^{10} BTU)	

a. Fraction of input activity (Table 4.2.1). Includes a DF of 10^4 for particulates in plant APS. Released over 250 days/yr.

4.2.3.8 Hulls Melting Facility Decommissioning Considerations

The life of the hulls melting facility is expected to be equivalent to the life of the processing facility. The equipment would be treated as TRU-contaminated waste for final disposal.

4.2.3.9 Hulls Melting Facility Postulated Accidents

The production melting of titanium by the consumable electrode arc process has over the years experienced several explosions. The accidents had the following common elements:

1. Ingots 30 cm (12 in.) in diameter were being melted.
2. Water contacted molten titanium.
3. The casualties and damage resulted from a hydrogen explosion.

In most cases the water leak was caused by the high-current, low-voltage dc arc melting through the crucible wall into the water jacket.

Production melting of zirconium is also accomplished by the consumable electrode arc process. Only one explosion, with minor consequences, has been reported with zirconium. This was in a furnace 23 cm (9 in.) in diameter. A hydrogen explosion did occur.

The Inductoslag process proposed for melting hulls is not currently being used as a production tool. However, in eight years of laboratory development hundreds of titanium and zirconium ingots have been melted up to 13 cm (5 in.) in diameter, and a water leak has never been experienced. The segmented crucible design consists of 12 separate coaxial water channels (for a crucible 10 cm in diameter, more for one 20 cm in diameter) fed in parallel from a water header located down and away from the molten metal zone. Should a water leak occur near the molten zone, it would probably be in a single segment. The amount of metal molten at any one time in a 20-cm (8-in.) crucible is about 25 kg (56 lb). Consequently, solidification is rapid after the power is turned off. The maximum amount of molten zirconium that would react with water in this instance is estimated to be 1 kg. Safety features make it highly unlikely that a water leak, should it occur, would result in an incident that would harm personnel or result in a difficult contamination problem. An accident of this nature is summarized as Accident 4.2.3 in Table 4.2.29. No accidents that could be classified as moderate or severe accidents could be realistically postulated for this technology.

TABLE 4.2.29. Hulls Melting Facility Minor Accidents

Accident No. and Description	Sequence of Events	Safety Systems	Release
4.2.3-Molten Zr explosion/fire. Estimated frequency ~0.2/yr	1. Water leak in lower crucible segment.	1. Automatic shutdown of equipment when water leak is detected by low pressure.	Activity in 1 kg of Zr hulls is released to process cell atmosphere. ³ H would be released as a gas. Cs, Te, Ru, and Rb are expected to act as particles. All others would either not vola- tilize or would plate out before reaching the facil- ity filters.
	2. Water flashes to steam.	2. Inert atmosphere with loss detection alarms.	
	3. Steam reacts with Zr to generate H ₂ .	3. Segmented water chan- nels to limit leaks.	
	4. H ₂ reacts explosively with O ₂ in air, rup- turing the melter.	4. Small molten pool and rapid solidification. 5. Independent control of power input, extraction rate and feed rate.	

The operator has a full view of the molten pool and crucible and has complete independent control over power input, ingot extraction rate, and feed rate. Any one, two, or three of these can be started or stopped during melting without producing a critical control situation or adversely affecting the resulting ingot quality.

Pyrophoricity of zirconium and the criticality hazard of packaged hulls are discussed in Section 4.2.1.9.

The percent undissolved fuel that can remain with the melted cladding hulls without exceeding the critical masses given in Section 4.2.1.9 is given for different fuel enrichments in Table 4.2.30.

TABLE 4.2.30. Allowable Percent Undissolved Fuel in Melted Hulls Canisters

Fuel Enrichment	Allowable % Undissolved Fuel
4% ^{235}U	0.24
5% ^{235}U	0.15
4% Pu	0.17
5% Pu	0.13

4.2.3.10 Hulls Melting Facility Costs

Estimates of capital, operating, and levelized unit costs are presented in mid-year 1976 dollars. A complete description of the cost estimate bases, assumptions, and definitions is given in Section 3.8.

Capital Costs. The capital cost estimate for the HMF is shown in Table 4.2.31 expressed in mid-year 1976 dollars. The estimate covers all capital costs specifically resulting from inclusion of the HMF as an integral part of the FRP described in Section 3.2.3. These costs also include the effect of incremental additions to utility supplies, such as electrical substation, HVAC, compressed air, and similar auxiliaries, as well as the cable, piping and other bulk materials incorporated directly into the HMF. However, general FRP costs for such services as laboratories and warehousing is not allocated to the HMF.

The total capital cost includes all plant-related costs incurred from the start of engineering to the start of commercial operation, excluding only working capital.

Operating Cost. The reference facility's annual operating cost is shown in Table 4.2.32. Direct labor costs are based on requirements given in Table 4.2.25. Process materials are based on requirements in Table 4.2.26. The canisters cost approximately \$8000 each. Estimates for utilities are based on requirements also given in Table 4.2.26. Annual maintenance material costs are estimated at 4% of the initial equipment investment. Overhead and miscellaneous costs are based on factors given in Section 3.8. The estimates for the miscellaneous items are assumed to include all unidentified operating costs. The costs of taxes, insurance, and interest, however, are included in the capital segment of the levelized unit cost.

TABLE 4.2.31. Capital Cost Estimate for Hulls Melting Facility

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		40	3,600	500	4,100
Buildings and structures		109	720	1,330	2,050
Bulk materials		180	3,100	2,200	5,300
Site improvements		1	20	10	30
Subtotal direct site construction costs		330	7,440	4,040	11,480
Indirect site construction costs	85	64	1,490	1,920	3,410
Total field cost	85	394	8,930	5,960	14,890
Architect-engineer services					2,800
Subtotal					17,690
Owner's cost					5,210
Total facility cost					22,900
Estimate accuracy range					±30%

TABLE 4.2.32. Hulls Melting Facility Operating Cost Estimate

Cost Element	Annual Costs, \$1000s
Direct labor	450
Process materials	1530
Utilities	100
Maintenance materials	160
Overhead	600
Miscellaneous	70
Total	2910 ±25%

Levelized Unit Cost. The levelized unit cost, including levelized capital and operating costs, is shown in Table 4.2.33. The unit cost calculation assumes private ownership of the facilities. Separate costs are shown for facilities shipping the canisters by truck or by rail since a special shipping facility costing \$900,000 would be required to handle rail casks. The operating costs for a rail or truck facility are not significantly different.

4.2.3.11 Hulls Melting Facility Construction Requirements

Many of the factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information which follows provides a basis for evaluating the impact of construction activities.

TABLE 4.2.33. Hulls Melting Facility
Levelized Unit Cost Estimate

Cost Element	Unit Cost, \$/kg HM	
	Truck Shipment	Rail Shipment
Levelized capital charge	2.80	3.00
Levelized operating charge	<u>1.40</u>	<u>1.40</u>
Levelized total unit cost	4.20 $\pm 35\%$	4.40 $\pm 35\%$

Project Schedules and Construction Manpower. The schedule for engineering, procurement, and construction of the HMF is an integral factor in the overall schedule for the FRP. This schedule is given in Section 3.2.3.7. The field labor force estimated for the construction phase of the HMF is tabulated below:

	Man-hours, <u>1000s</u>
Manual field labor	394
Nonmanual field labor	<u>85</u>
Total field labor	479

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials, and services provided at the site of the FRP while offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is as shown below:

	Costs, <u>1000s</u>
Onsite	6,400
Offsite	<u>16,500</u>
Total	22,900

Site Requirements. This facility will share the same site as the FRP. No additional site requirements beyond those for the FRP are identifiable.

Water. About 800 m^3 (2.1×10^6 gal) are required during the construction period.

Construction Materials. Materials committed to construction of the HMF are:

Concrete	2,220 m^3	(2,900 yd^3)
Steel	580 MT	(640 tons)
Copper	15 MT	(17 tons)
Zinc	0.9 MT	(1 ton)
Lumber	140 m^3	(60 MFBM)

Energy. Energy resources used during construction will be:

Propane	60 m ³	(16,000 gal)
Diesel fuel	720 m ³	(190,000 gal)
Gasoline	360 m ³	(96,000 gal)
Electricity:		
Peak demand	430 kW	
Total consumption	280,000 kWh	

Transportation Requirements. No separately defined transportation requirements for the HMF have been identified beyond those for the FRP.

4.2.3.12 Effects of Fuel Cycle Options

See Section 4.2.1.12.

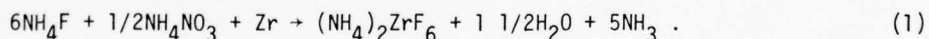
4.2.4 Other Alternatives for Treating Fuel Residue

Alternative processes which could be used to treat hulls include:

1. Dissolution in sulfuric acid or in fluoride solution.
2. High-temperature oxidation in O₂-HF.
3. Reaction with HCl to form volatile ZrCl₄, followed by pyrohydrolysis to ZrO₂.
4. Production of zirconate useful as an adsorbant for radionuclides from HLLW.

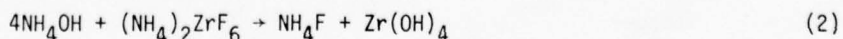
These processes are in varying stages of development; however, none with the possible exception of process 4 appear at this time sufficiently attractive to warrant further extensive developmental work.

Several chemical processes employ fluoride-bearing solutions to dissolve Zircaloy cladding. One of the better known processes, the Zirflex process, utilized NH₄F-NH₄NO₃ as the solvent:



A 10,000-gal stainless steel dissolver would be adequate to dissolve (one dissolution/day) the Zircaloy produced daily, assuming a production rate of 8 MTHM/day. A small amount of hydrogen as well as ammonia is produced during dissolution of Zircaloy.⁽¹⁸⁾ Air or steam dilution of the off-gas to <4% H₂ and 16% NH₃ is therefore necessary to avoid explosive mixtures.

It has been reported⁽¹⁹⁾ that adding ammonia to the spent cladding dissolution solution regenerates NH₄F with simultaneous precipitation of hydrous zirconia:



If feasible, this procedure would markedly reduce the amount of fluoride sent to storage. The volume ratio of hydrous zirconia to Zircaloy hulls is about 0.6. Developmental work would be required to determine a feasible process for disposal of the dissolved waste.

Dissolution of Zircaloy is also possible in hot concentrated sulfuric acid. However, problems with materials as well as the product form, $\text{Zr}(\text{SO}_4)_2$, make the process less attractive than dissolution in fluoride solution.

Both Zircaloy and stainless steel are smoothly and rapidly converted to oxides by exposure for 1 to 4 hr at 500 to 625°C to gas mixtures containing 30 to 65% HF and 70 to 35% O_2 .⁽²⁰⁾ Development work to date has utilized fluidized bed reactors employing alumina as the fluidized medium. No development work with irradiated Zircaloy has been reported. Thus, information is not available on the fate and disposition of radionuclides during the oxidation step. Though most of the radionuclides would probably be converted to nonvolatile oxides, some would be converted to fluoride compounds, and others would volatilize. Provisions would be required for trapping and disposing of these materials.

Zircaloy can be volatilized as ZrCl_4 by reaction with HCl at about 400°C in a fluidized bed employing alumina as the fluidized medium or in an open tube reactor. Alternatively, chlorination may be achieved by reaction with molten zinc chloride at about 500°C. This latter procedure offers the advantage of incorporating the residual constituents in a medium that is not easily dispersed. However, quantitative volatilization of ZrCl_4 from molten ZnCl_2 may offer some difficulty.⁽²¹⁾ In the conceptual process ZrCl_4 would be converted to the final product, ZrO_2 , by pyrohydrolysis with steam at about 350°C. The reaction with ZnCl_2 might be carried out in a tungsten crucible in an inert gas atmosphere, whereas nickel equipment can be used when chlorination by HCl is employed. No development work has been done with irradiated Zircaloy or stainless steel; thus the fate and disposition of radionuclides associated with these materials are unknown.

Processes are currently being explored for making zirconate ion exchange resin from Zircaloy cladding suitable for use as an absorbent for radionuclides from HLLW. An outline of such a conceptual process is available.⁽²²⁾ Substantially more development work is required before the usefulness of this process can be established.

Studies in progress to determine effective decontamination procedures for hulls may result in procedures very useful at a later date.⁽²³⁾ One procedure consists of exposing hulls to HF at 600°C and then treating them in fluoride solution. Analysis indicated about 99.7% of the residual alpha activity was removed. Recycle of this material may be feasible.

The above processes are not sufficiently developed to allow consideration for use in a commercial fuels reprocessing facility. The systems presented in Sections 4.2.1, 4.2.2, and 4.2.3 were selected for consideration because designs for such processes are now available and quantitative information on process requirements can be determined.

4.2.5 Physical Protection and Safeguard Requirements for Fuel Residue Packaging

Packaged fuel residue would not be an attractive target for theft or sabotage. The radioactive material would consist mainly of long-lived activation products. Fission products and actinides (plutonium and others) would be several orders of magnitude below those in spent fuel. The contained radioactive material would be extremely difficult to disperse because nearly all

of the waste would be in compact metallic form. A further deterrent would be that the containers would be heavy (1.4-m^3 volume), and their surface dose rate would exceed 10 R/hr, requiring heavy shielding for biological protection of anyone handling them.

There is a low probability that an insider could sabotage the plant by way of minor fire damage from the burning of micron-size zirconium fines before their deactivation with sand. The consequences might be similar to those for Accident 4.2.1, Table 4.2.8.

Initial treatment of fuel bundle residues would be in a vital area. The required physical protection measures for vital areas would be adequate for safeguarding the treatment of this material. When the package residues are moved out of the vital area, the physical protection required for the balance of the plant will secure these wastes.

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4.3 FAILED EQUIPMENT AND NONCOMBUSTIBLE WASTE
TREATMENT

4.3 FAILED EQUIPMENT AND NONCOMBUSTIBLE WASTE TREATMENT

Failed equipment and noncombustible waste are among the solid wastes produced during the operation of fuel reprocessing plants (FRPs) and mixed oxide fuel fabrication plants (MOX FFPs). The generation of small items of noncombustible waste is more or less routine and predictable in a nuclear facility. The failure of large items of radioactive process equipment is not routine, however, and can have a serious effect on operating schedules. Rapid replacement of such equipment is essential to plant efficiency; prompt treatment, including equipment disassembly and packaging for early removal from the processing area, is also vital.

4.3.1 Failed Equipment and Noncombustible Waste Treatment at an FRP

Much of the information in this section is based on information given in the Final Safety Analysis Report for the Barnwell Nuclear Fuel Plant Separations Facility.⁽¹⁾ Allowances have been made for the larger capacity of the reference facility (2000 MTHM/yr versus 1500 MTHM/yr for the Barnwell plant).

Metal is the primary constituent of FRP failed equipment and noncombustible waste, but substances such as glass and concrete are also present. Incidental quantities of combustible material such as grease, plastic, and floor sweepings are included with the noncombustible waste. Reprocessing plant canyon operations provide the largest and most radioactive pieces of failed equipment. Typical large items are dissolvers, columns, and concentrators, any of which might be up to 3 m (10 ft) in diameter and 10 m (30 ft) in height. Noncombustible scrap will probably include small hand tools that cannot be economically decontaminated, used light bulbs, wire ends, electrical panels, metal scraps, and glasswares from contaminated areas, and all heating, ventilating and air conditioning components and accessories within a possibly contaminated system.

FRP operations cover the extremes of contamination and radiation levels. Failed equipment and noncombustible waste will be generated in areas such as the process canyon (shielded process rooms), the fuel storage basin, the contact maintenance cells, the UF_6 facility, and the plutonium processing areas. The waste from these various sources can be generally categorized as those which are high-gamma wastes from the process canyon and those which are not. Provisions are made for switching waste from one category to the other if its characteristics are changed during the treatment operation. Almost all FRP radioactive wastes are contaminated with transuranics. Exceptions include wastes from the UF_6 facility and the spent fuel storage basin; wastes from these sources can be kept free of transuranic (TRU) waste. Some failed equipment may be contaminated to such a low level that it can be classified as non-TRU waste.

4.3.1.1 Alternatives for Treating Failed Equipment and Noncombustible Waste at the FRP

Review of waste treatment at the FRP shows that failed equipment is usually subjected to some degree of decontamination to allow disassembly for packaging into waste containers. Some failed equipment items and most noncombustible waste can be packaged directly without decontamination or disassembly. Other failed items may be decontaminated but do not require

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dismantling before packaging. Alternative procedures for decontamination, disassembly, and packaging of failed equipment and noncombustible wastes are presented in the following paragraphs.

Decontamination. Procedures commonly used for decontamination of failed equipment include: 1) flushing with water, 2) leaching with strong chemical solutions, 3) steam scrubbing, 4) high-pressure washdown with water, 5) mechanical brush scrubbing, 6) ultrasonic cleaning and 7) vacuum cleaning. Noncombustible waste may also be decontaminated by these methods; items such as dead batteries and failed light bulbs, however, are not decontaminated.

Generally, all of the above procedures for decontamination are available to the operator at the FRP. The choice to be made is in the degree of application. Considerable activity could be removed from failed equipment by prolonged and rigorous application of available methods, but it is not clear that such efforts would consistently be economical or yield a net reduction in volumes of waste requiring disposal. For this study, decontamination efforts for FRP failed equipment are assumed to remove sufficient contamination to facilitate disassembly and packaging. For this purpose, a removal of 95% of the contamination on failed equipment is assumed. Even with this assumed degree of decontamination, shielding of some of the waste packages will be required. No decontamination of other noncombustible waste is assumed. This decontamination procedure is selected on the basis of prior experience in FRP operations.

Disassembly. The goal for disassembly of failed equipment is to reduce its size to allow packaging for shipment and disposal. Procedures available for equipment disassembly are the following: 1) dismantling into component parts, 2) cutting with torches or abrasive saws, 3) shredding, and 4) collapsing by compaction (similar to auto compactors). Cutting with properly located plastic explosives could also be used. Procedures assumed for this study are based on technically feasible operations and include dismantling into component parts and cutting with torches and abrasive saws. A standard ram is assumed available for compaction of light, bulky items. Because of the inability to decontaminate sufficiently, some of these operations will be done remotely. Only the failed equipment items that cannot be packaged directly will be disassembled.

Packaging. The procedures used for decontamination and disassembly dictate the packaging requirements. If rigorous decontamination and disassembly of failed equipment is employed, packaging could be accomplished by direct contact operations. Thorough decontamination of noncombustible scrap would also allow its packaging by direct, hands-on contact. Alternatively, waste receiving no decontamination would require remote packaging operations. Packaging may be performed with or without compaction into waste containers. This study assumes availability of both remote and direct contact facilities for packaging. Wastes are packaged in drums, canisters, and boxes as described in the following section.

4.3.1.2 Design Basis for Treating Failed Equipment and Noncombustible Waste at the FRP

Facilities for treatment of failed equipment and noncombustible waste are provided by expanding the capacity of various multipurpose shops and cells that are an integral part of

4.3.3

the FRP. Areas devoted exclusively to treating these wastes are not required since this treatment is closely related to facility maintenance and housekeeping.

Annual volumes of failed equipment and noncombustible wastes are estimated to be 440 m³ (16,000 ft³) and 960 m³ (34,000 ft³), respectively. The activity assumed present in the waste is summarized in Table 4.3.1. Primary wastes are generated from operation of the FRP main separation process, while secondary wastes are those that result from waste treatment tasks. Decontamination of the failed equipment is assumed to remove 95% of the associated activity shown in Table 4.3.1. This decontamination solution, with a volume of 820 m³ (220,000 gal)/yr, is concentrated to give 20 m³ (5300 gal)/yr of secondary wet waste, the treatment of which is described in Section 4.7.

TABLE 4.3.1. Activity in Untreated Failed Equipment and Noncombustible Waste at the Fuel Reprocessing Plant(a)

Radionuclide	Ci/yr			
	Main Plant Waste		PuO ₂ Conversion Waste	
	Failed Equipment(b)	Noncombustible Waste(c)	Failed Equipment(d)	Noncombustible Waste(e)
Fission products				
³ H		13		
¹²⁹ I		2.1 x 10 ⁻⁶		
⁹⁰ Sr + ⁹⁰ Y	240	2,600		
⁹⁵ Zr + ⁹⁵ Nb	22	240		
¹⁰⁶ Ru + ¹⁰⁶ Rh	760	8,400		
¹³⁴ Cs + ¹³⁷ Cs + ^{137m} Ba	600	6,600		
¹⁴⁴ Ce + ¹⁴⁴ Pr	960	11,000		
All other FPs	200	2,200		
Total	2,782	31,040		
Actinides				
²³⁹ Pu	0.72	0.76	70	70
²⁴¹ Pu	350	370	34,000	34,000
other Pu	13	13	1,300	1,300
Cm ²⁴² + Cm ²⁴⁴	34	370		
All other actinides	1.8	20		
Total	400	774	35,370	35,370
Activation products				
⁵⁵ Fe		800		
⁶⁰ Co		800		
⁹⁵ Zr + ⁹⁵ Nb		34		
All others		800		
Total		2,434		

a. Based on waste characterization Table 3.3.35 and secondary waste Table 3.5.1, assuming uranium and plutonium recycle, 2000 MTHM/yr reprocessed 1.5 years out of reactor.

b. Volume - 400 m³/yr; density - 500 kg/m³.

c. Made up of 800 m³/yr of primary waste and 150 m³/yr of secondary waste; density - 250 kg/m³.

d. Volume - 40 m³/yr; density - 500 kg/m³.

e. Volume - 12 m³/yr; density - 250 kg/m³.

4.3.4

4.3.1.3 Procedures For Treating Failed Equipment and Noncombustible Waste at the FRP

A schematic flow diagram illustrating the reference treatment procedures for failed equipment and noncombustible waste is shown in Figure 4.3.1. Noncombustible trash is not decontaminated before packaging but may go to interim storage until packaging operations are started. All noncombustible trash is packaged in 55-gal drums, some of which will require shielding for personnel protection. Packaging of this trash will, therefore, be done in both shielded cells and facilities such as unshielded gloveboxes or hoods, depending on the activity level encountered. Lids are placed on filled drums and are secured with ring-clamps.

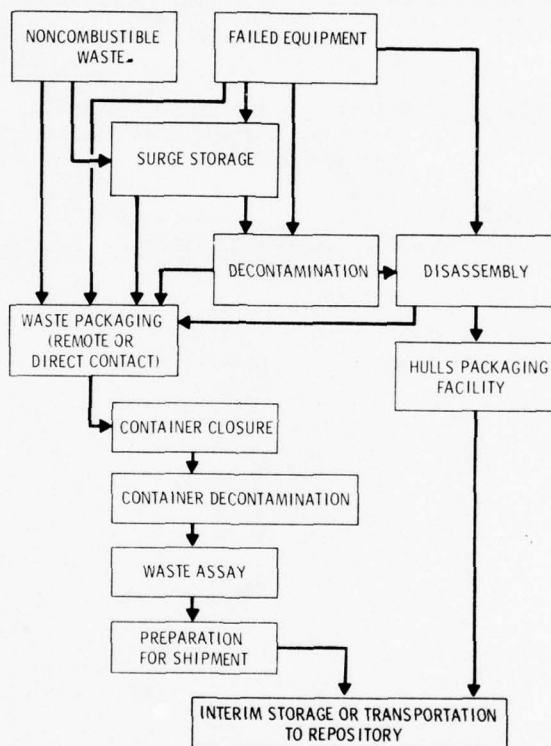


FIGURE 4.3.1. Process Flow Diagram for Treating Failed Equipment and Noncombustible Waste at the Fuel Reprocessing Plant

Contamination of waste packages is reduced by enclosing the package in plastic bags during filling and closure operations. The bags are removed as the container is transferred from the contaminated zone to the decontamination area, where any remaining contamination on the surface is removed. Waste containers are then assayed for gamma radioactivity level, prepared for shipment, and either stored in interim facilities or transported to waste isolation facilities. Drums with surface dosages of over 200 mrem/hr require shielding for personnel protection during handling, shipment, and storage.

4.3.5

As Figure 4.3.1 shows, failed equipment is handled in several ways, depending on its size and the degree of contamination. Some items that do not require decontamination and that will fit in carbon steel boxes 1.2 x 1.8 x 1.8 m (4 x 6 x 6 ft) can go directly to the packaging facilities with or without temporary storage. Only low activity failed equipment is packaged in these boxes. Failed equipment that requires decontamination to allow disassembly or packaging in boxes may be sent directly to the remote decontamination facility or stored temporarily until decontamination operations can be started. Failed equipment that cannot be decontaminated sufficiently to allow packaging in boxes (the boxes must have a surface dose rate less than 200 mrem/hr) or that cannot be disassembled to fit in drums is packaged in hulls canisters in the hulls packaging facility described in Section 4.2.

Decontamination and disassembly of failed equipment is effected by means described in Section 4.3.1.1.

Treatment in this task will yield waste packages with different surface dose rates. The dose rates from packaged FRP primary noncombustible waste and decontaminated FRP failed equipment were calculated to range from 100 to 400,000 mrem/hr and 100 to 4,000 mrem/hr, respectively, at the surface of the waste drum or box. Calculations of dose rates from FRP PuO₂ conversion plant noncombustible trash and FRP PuO₂ conversion plant failed equipment averaged 100 mrem/hr and 0.6 mrem/hr, respectively, at the surface of the waste packages. On the basis of these average surface dose rates, a distribution of treated waste dose rates was estimated and is shown in Table 4.3.2 along with the container sizes and numbers.

TABLE 4.3.2. Description of Packages of Treated Failed Equipment and Noncombustible Waste at the Fuel Reprocessing Plant

Waste by Surface Dose Rate Class, R/hr	Volume, ^(a) m ³ /yr	Density, kg/m ³	Volume Ratio ^(a) Treated/Untreated	Containers/yr			Radioactivity Factor ^(e)		
				Drums ^(b)	Boxes ^(c)	Canisters ^(d)	Fission Products	Actinides	Activation Products
Main plant noncombustible waste									
<0.2	90	250	1.0	431	--	--	4.6 x 10 ⁻⁴	0.0026	
0.2 - 1	312	250	1.0	1500	--	--	0.0084	0.048	
1 - 10	404	250	1.0	1940	--	--	0.081	0.46	
>10	104	250	1.0	500	--	--	0.91	0.49	1.0
Main plant failed equipment									
<0.2	204	500	1.0	--	50	--	0.0054	0.0052	
0.2 - 1	186	500	1.0	445	--	67	0.029	0.028	
1 - 10	11	500	1.0	26	--	4	0.016	0.015	
PuO ₂ plant noncombustible waste									
<0.2	11	250	1.0	52	--	--		0.58	
0.2 - 1	1.2	250	1.0	6	--	--		0.42	
PuO ₂ plant failed equipment									
<0.2	41	500	1.0	--	10	--		0.05	

a. Treated volume based on container volume.

b. 55-gal drums (0.208 m³).

c. 1.2 x 1.8 x 1.8 m (4.08 m³).

d. 75-cm dia, 3 m long (1.39 m³).

e. Radioactivity in packages, fraction of corresponding input (Table 4.3.1).

4.3.6

4.3.1.4 Description of Facilities for Treating Failed Equipment and Noncombustible Waste at the FRP

Facilities are provided in the main process building of the FRP for decontaminating, disassembling and packaging contaminated failed equipment and noncombustible radioactive trash in a manner commensurate with contamination and radiation levels. Treatment of these wastes is carried out in various multipurpose shops and cells designed for general FRP maintenance; areas devoted exclusively to treating failed equipment and noncombustible wastes are not required.

Remote Decontamination Cell. The remote decontamination cell is used to decontaminate highly radioactive process equipment. This cell is lined with stainless steel and is equipped with shielding windows, a master-slave manipulator, an ultrasonic cleaner, a turntable, work benches, a transfer hatch to the high-level maintenance shops, an overhead crane and a ventilation filtration system. About 25% of the operation in this cell is expected to be required to decontaminate failed or obsolete equipment for disposal.

High-level Maintenance Shop. This shop has facilities for remote disassembly of failed equipment. Once disassembled, the pieces of equipment are removed from the cell through access hatches and placed in shielded containers for disposal. The floor and walls of the cell are lined with stainless steel. The shop is equipped with shielding windows, master-slave manipulators, pass-through ports, periscopes, a power manipulator, shielding hatches, work benches, tool racks, tools adapted for remote operation, a turntable and an overhead crane. About 18% of this facility is expected to be required for disassembly and packaging of failed or obsolete equipment.

Contact Maintenance Shops. These shops are used to manipulate and repair equipment that is not contaminated to a high radiation level. It is estimated that 25% of the equipment handled through these facilities will not be repairable and will be discharged as solid waste. Contact maintenance shops include the following facilities:

- Manipulator repair shop. This shop is designed to provide parts storage for short-term needs, decontamination areas for wipedown of slave ends, small parts decontamination equipment, scaffold supports and a bridge crane for manipulator handling.
- Crane and equipment maintenance gallery. This facility permits the maintenance of cranes serving various cells in the remote processing cells. The major equipment in the crane and equipment maintenance gallery includes maintenance cranes, a shielded door, an ultrasonic cleaning tank, and a shielded viewing window.
- Contact equipment removal station. This facility provides entry into a contact cell in the event in-cell equipment requires repair or replacement. Major component for maintenance purposes is a 60-ton bridge crane.

4.3.7

- Equipment maintenance station. This station is a general equipment maintenance shop equipped with shielded plugs to other areas, work table and bench, an ultrasonic cleaning tank and tool cabinets.
- Plutonium oxide equipment maintenance glovebox. Maintenance operations for plutonium oxide conversion process equipment are performed in gloveboxes. Neutron shielding is provided. Decontamination is accomplished by vacuuming and wiping. A crane, hand tools, and a bag-in/out station are provided in the glovebox enclosure.

Chemical Storage and Makeup Area. This area provides space for the storage of additional decontamination chemicals and the preparation of decontamination solutions. Thirty percent of this facility is expected to be used for decontamination of failed equipment.

Closure Facilities. Welding facilities are required for closing boxes, and an area for drum closure is needed.

Shielding and Remote Handling Equipment. Remote techniques are a necessity for handling the highly radioactive failed equipment coming from the process canyon. Remotely operated cranes, manipulators, and special tools will be used with such equipment. Personnel will be protected by massive radiation shielding and will view their work via shielding windows or closed circuit television. All TRU-contaminated material will be handled in a manner that will protect employees from plutonium contamination. Waste packages with surface dose rates in excess of 200 mrem/hr (as indicated in Table 4.3.1) will require shielding.

4.3.1.5 Operating and Maintenance Requirements for Treating Failed Equipment and Noncombustible Waste at the FRP

The removal of small-sized pieces of solid noncombustible waste in an FRP is similar to a housekeeping chore and presents no serious problem. Conversely, the failure of a large piece of processing equipment may be a major event requiring the efforts of a large part of the plant personnel. Recovery efforts may continue around the clock until the plant is back in operation. Disposal of the failed equipment will be integrated with the maintenance effort but may not be completed until after the plant is back in operation.

Since failed equipment and noncombustible wastes are treated in the same facilities used for general FRP maintenance, there are no significant maintenance requirements over and above those of the FRP as a whole.

Procedures for decontamination, disassembly, and packaging operations are established to protect personnel from radiation and contamination. Handling requirements will vary according to the operation performed and the radiation level of the equipment involved. Careful planning and monitoring of all FRP failed equipment treatment operations are also required because of the potential hazards associated with the use of strong chemicals for the decontamination effort.

Staffing. Table 4.3.3 presents estimated staffing requirements for failed equipment and noncombustible waste treatment.

4.3.8

TABLE 4.3.3. Staffing Requirements for FRP Failed Equipment and Noncombustible Waste Treatment

<u>Job Description</u>	<u>Personnel Required, man-yr/yr</u>
Operators	3.4
Radiation monitors	0.4
Maintenance craftsmen	3.4

Supplies and Utilities. Estimated acetylene and electricity requirements for the reference waste treatment are given in Table 4.3.4.

TABLE 4.3.4. FRP Failed Equipment and Noncombustible Waste Treatment Utility Requirements

<u>Utility</u>	<u>Use Rate</u>	<u>Annual Requirement</u>
Electricity	350 kW	7×10^5 kWh
Acetylene	1 kg/hr	500 kg

4.3.1.6 Secondary Radioactive Wastes for Failed Equipment and Noncombustible Waste Treatment at the FRP

Estimates of secondary radioactive wastes for the reference treatment task are shown in Table 4.3.5.

TABLE 4.3.5. Secondary Radioactive Wastes for Treating FRP Failed Equipment Noncombustible Waste

<u>Description</u>	<u>Volume, m³/yr</u>	<u>Radioactivity Factor</u>
Combustible and compactable waste	20	$1 \times 10^{-6(a)}$
Concentrated wet waste	20	$0.95^{(b)}$
Failed equipment	0.2	$1 \times 10^{-4(a)}$

a. Fraction of total input activity (Table 4.3.1) in secondary wastes.

b. Fraction of input activity on failed equipment (Table 4.3.1) in secondary wastes.

4.3.1.7 Emissions from Failed Equipment and Noncombustible Waste Treatment at the FRP

Estimated emissions are given in Table 4.3.6. The controlling emission to the stack results from concentrating the solutions used for failed equipment decontamination. Emissions from entrainment of loose contamination in cell ventilation air are insignificantly small compared to the concentrator emissions.

4.3.1.8 Decommissioning Considerations for Facilities for Treating FRP Failed Equipment and Noncombustible Waste

The failed equipment treatment sections of the FRP are incidental to the overall plant and do not have special decommissioning considerations.

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TABLE 4.3.6. Emissions from Failed Equipment and Noncombustible Waste Treatment at FRP

Emission	Description	Annual Quantity	Radioactivity Release Factor to Atmosphere
Gaseous	Ventilation air	$2 \times 10^8 \text{ m}^3$	$1 \times 10^{-15} \text{ (a)}$
	Vaporized excess water	$8 \times 10^5 \text{ kg}$	$2 \times 10^{-9} \text{ (b)}$
	Minor accident integrated annual release		None identified

- a. Fraction of input activity on noncombustible trash (Table 4.3.1) released to atmosphere. Includes DF from main plant APS. Released over 300 days/yr.
- b. Fraction of input activity on failed equipment (Table 4.3.1) released to atmosphere via FRP general purpose concentrator and excess water vaporizer. Released over 300 days/yr.

4.3.1.9 Postulated Accidents for FRP Failed Equipment and Noncombustible Waste Treatment

The operations of decontamination, disassembly, and packaging are conducted within a facility that is designed to withstand natural events that might be expected at the plant site, as well as a credible number of other types of accidents or errors. During disassembly efforts, there is a potential for removing pieces without proper support, causing the failed unit to tip over. Failed equipment could also be dropped from the crane while removing the equipment from service. Such incidents are described as postulated minor accidents in Table 4.3.7.

TABLE 4.3.7. Minor Accidents for Failed Equipment and Noncombustible Waste Treatment at the Fuel Reprocessing Plant

Accident No. and Description	Sequence of Events	Safety Systems	Release
4.3.1-Failed equipment tips over during disassembly.	1. Large equipment unit fails.	1. Remote handling protects personnel.	None.
	2. Unit is removed from service.	2. Operating procedures are prepared and reviewed prior to initiation of disassembly.	
	3. Unit is prepared for disassembly.		
	4. Support removed from unit.		
	5. Unit tips over.		
	6. Disassembly for packaging is completed.		
4.3.2-Failed equipment dropped from crane.	1. Large equipment unit fails.	1. Attachment to crane is checked before transfer begins.	None.
	2. Unit is prepared for removal from service.	2. Lift height is restricted to that necessary to clear obstacles.	
	3. Poor attachment to crane results in drop during transfer to maintenance area.	3. Operations are remote to protect personnel.	
	4. Unit is secured to crane and transfer is completed.		

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Cutting torches used to disassemble and decontaminate the failed equipment represent a possible fire source; however, no combustible items are handled in this task.

No accidents that could be classified as moderate or severe accidents could be realistically postulated for this technology.

4.3.1.10 Costs for Failed Equipment and Noncombustible Waste Treatment at the FRP

Estimates of capital, operating and levelized unit costs are presented in mid-year 1976 dollars. A complete description of the cost estimate bases, assumptions, and definitions is given in Section 3.8.

Capital Costs. The capital cost estimate for these facilities is shown in Table 4.3.8. Few areas of the FRP can be identified as exclusively used for the treatment of failed equipment and noncombustible waste. Because the inclusion of such waste treatment functions may increase the FRP facility sizes and capacities, however, a part of the basic cost is charged to the treatment of failed equipment and noncombustible waste. The proportion of the cost that is charged is based on the assumption that the waste treatment would require additional space and sharing of equipment in the dual-function facilities.

TABLE 4.3.8. Capital Cost Estimate for Facilities for Failed Equipment and Noncombustible Waste Treatment at the Fuel Reprocessing Plant

Cost Element	Man-hours, 1,000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		30	4,000	400	4,400
Buildings and structures		150	1,200	1,800	3,000
Bulk materials		120	2,800	1,400	4,200
Site improvements					
Subtotal of direct site construction costs		300	8,000	3,600	11,600
Indirect site construction costs	80	60	1,500	1,900	3,400
Total field cost	80	360	9,500	5,500	15,000
Architect-Engineer services					3,000
Subtotal					18,000
Owner's cost					5,000
Total facility cost					23,000
Estimate accuracy range					±50%

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The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation, with the exception of working capital. The accuracy range reflects uncertainties in the engineering scope required and in the pricing and quantities for labor, materials, and equipment. Because of the difficulties in estimating the quantities of failed equipment and noncombustible trash, the proportion of the waste treatment system which is charged to the handling of such wastes is not well defined. The lack of a well-defined physical interface between the facilities for waste treatment and the facilities designed for plant maintenance and routine wastes also contributes to estimate uncertainty.

A contingency covering these and similar factors has been included in the base estimate. With the contingency included, there is an approximately equal likelihood of an overrun or underrun on the indicated cost.

Operating Costs. Direct labor and utilities costs are based on requirements given in Tables 4.3.3 and 4.3.4. Process materials for equipment disassembly and packaging at the FRP consist mainly of the drums, boxes and 76 cm diameter by 3.1 m long canisters used for packaging. Drums and boxes are estimated to cost \$20 per drum and \$400 per box, respectively. The canisters are estimated to cost \$8000 each. Maintenance materials costs are estimated at 3% of major equipment. Labor costs include a provision for remote maintenance labor. Table 4.3.9 summarizes the operating costs.

TABLE 4.3.9. Operating Cost Estimate for Failed Equipment and Noncombustible Waste Treatment at the Fuel Reprocessing Plant

Cost Element	Annual Costs, \$1000s
Direct labor	330
Process materials	680
Utilities	10
Maintenance materials	130
Overhead	200
Miscellaneous	70
Total	1400 +50% -25%

Levelized Unit Costs. The levelized unit cost, including levelized capital and operating costs, is shown in Table 4.3.10. The unit cost calculation assumes private ownership of the facilities and a 15-yr economic life.

TABLE 4.3.10. Levelized Unit Cost Estimate for Failed Equipment and Noncombustible Waste Treatment at the Fuel Reprocessing Plant

Cost Element	Unit Cost, \$/kgHM
Levelized capital charge	2.90
Levelized operating charge	.70
Levelized total unit cost	3.60 ±55%

4.3.1.11 Construction Requirements for Facilities for Failed Equipment and Noncombustible Waste Treatment at the FRP

Fuel reprocessing plant construction activities and requirements may have some impact on the environment and economy of the surrounding area. The information that follows provides a basis for evaluating any impact specifically attributable to the inclusion of failed equipment and noncombustible waste treatment functions in the designs for equipment maintenance and solid waste handling facilities at the reference FRP. Such an impact is determined by charging a percentage of the total impact of FRP construction to failed equipment and noncombustible waste facilities.

Project Schedules and Construction Manpower. The schedule for engineering, procurement and construction of the failed equipment and noncombustible waste treatment facilities is an integral factor in the overall schedule for the FRP. This schedule is described in Section 3.2. The field labor force estimated for the construction of the failed equipment and noncombustible waste treatment facilities is tabulated below.

	Man-hours, 1000s
Manual field labor	360
Nonmanual field labor	80
Total field labor	440

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials and services provided at the site of the FRP, while offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is shown below:

	Costs, \$1000s
Onsite	6,000
Offsite	17,000
Total	23,000

Site Requirements. Land commitments for the reference waste treatment facilities are included with those of the FRP.

Water. Approximately 5700 m^3 (1.5×10^6 gal) of water are required during the construction period.

Construction Materials. Construction materials committed to the facility are:

Concrete	3200 m^3	(4200 yd^3)
Steel	900 MT	(1000 tons)
Copper	9 MT	(10 tons)
Aluminum	4.5 MT	(5 tons)
Lumber	240 m^3	(100 MFBM)

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Energy. Energy resources used during construction will be:

Propane	57 m ³	(15,000 gal)
Diesel	570 m ³	(150,000 gal)
Gasoline	380 m ³	(100,000 gal)
Electricity		
Peak demand	380 kW	
Total consumption	250,000 kWh	

Transportation Requirements. No transportation requirements for the failed equipment and noncombustible waste treatment facilities have been identified beyond those for the FRP.

4.3.1.12 Effects of Fuel Cycle Options

Treatment of failed equipment and noncombustible waste at the FRP is based on closure of the LWR fuel cycle by recycling recovered uranium and plutonium. The effects of alternative fuel cycles on this treatment facility are as follows:

No Recycle. No treatment facility is required for this fuel cycle option.

Uranium Recycle Only, with Plutonium to a Repository. The requirements for this fuel cycle option are the same as the reference option for treatment of failed equipment and noncombustible waste.

Uranium Recycle Only, with Plutonium to HLW. A slight reduction in the volume of failed equipment and noncombustible waste that is generated in the reference option results from assuming this fuel cycle option. The volume reduction is attributable to the absence of a PuO₂ plant. The wastes eliminated are all low activity TRU wastes.

4.3.2 Failed Equipment and Noncombustible Waste Treatment at a Mixed Oxide Fuel Fabrication Plant

Noncombustible wastes generated in a mixed oxide fuel fabrication plant (MOX FFP) consist primarily of metals, glass and mineral forms. The metallic portion coming from glovebox enclosures includes a mixture of scrap fuel cladding, failed equipment, ventilation ducts, metal packaging material, and transfer containers used in moving material with the gloveboxes.

Noncombustible wastes from the operating area outside the glovebox enclosures are considered TRU-suspect and handled as TRU waste. Examples are discarded tools and equipment, outer packaging cases, and miscellaneous items such as spent assault-masks canisters. Glass would be in the form of discarded laboratory ware and empty reagent bottles.

4.3.2.1 Alternatives for Treating Failed Equipment and Noncombustible Waste at the MOX FFP

Alternatives for treating MOX noncombustible wastes are similar to the alternatives given in Section 4.3.1.1 for FRP wastes. Decontamination alternatives include the use of steam, high pressure liquids, mechanical scrubbing, or corrosive chemicals. The particular system used depends primarily on the activity level and configuration of the item being decontaminated. The disassembly alternatives are limited to standard techniques used by maintenance

personnel in repairing equipment. This includes the use of hacksaws, cutting torches, and shears to reduce material to a convenient size for handling and packaging. Decontamination at the reference MOX plant is assumed to be for failed equipment only. The activity removed by the decontamination solution is assumed to be 95% of the activity on failed equipment.

4.3.2.2 Design Basis for Treating Failed Equipment and Noncombustible Waste at the Mixed Oxide Fuel Fabrication Plant

Multifunctional areas in the MOX FFP used for general facility maintenance and waste treatment are expanded to accommodate treatment of failed equipment and noncombustible wastes.

The annual volumes of failed equipment and noncombustible wastes are estimated to be 80 m^3 (2800 ft^3) and 82 m^3 (2900 ft^3), respectively.

Activity assumed present in the wastes are summarized in Table 4.3.11. Primary wastes are generated from operation of the MOX FFP, while secondary wastes result from waste treatment tasks. Decontamination of failed equipment is assumed to remove 95% of the associated activity. The decontamination solution, with an annual volume of 40 m^3 (11,000 gal), is concentrated to give 1.6 m^3 (420 gal)/yr of secondary wet waste.

TABLE 4.3.11. Activity in Untreated Failed Equipment and Noncombustible Waste at the MOX FFP(a)

	Ci/yr	
	Failed Equipment(b)	Noncombustible Waste(c)
Actinides		
^{239}Pu	5.2	52
^{241}Pu	2,300	23,000
Other Pu	92	920
All other actinides	3.8	38

a. Based on waste characterization Table 3.3.40 and secondary waste Table 3.5.2, assuming 400 MTHM MOX fuel fabricated 1 year after plutonium purification.

b. Volume, $80 \text{ m}^3/\text{yr}$; density, $1000 \text{ kg}/\text{m}^3$.

c. Made up of $80 \text{ m}^3/\text{yr}$ of primary waste and $2 \text{ m}^3/\text{yr}$ of secondary waste; density $250 \text{ kg}/\text{m}^3$.

4.3.2.3 Procedures for Treating Failed Equipment and Noncombustible Waste at the MOX FFP

The Westinghouse plant described in Docket 70-1432, Vol. 1 and 2, is the principal reference for the operations described in this section.⁽²⁾ This plant design is representative of large production-scale plants currently under consideration. Actual operating experience for MOX plants, though, has been limited to small pilot plants or to laboratory-scale operations. However, the considerable experience in waste handling operations in defense plutonium plants

is applicable to these operations. Figure 4.3.2 is a simplified process flow sheet illustrating the sequence of operations. Table 4.3.12 characterizes the treated waste.

The general procedure followed in processing noncombustible glovebox wastes is to begin by removing from the waste items all loose contaminate dust, using brushes and vacuum cleaners. Items are then removed through a bag-out procedure and transferred to the decontamination and packaging area.

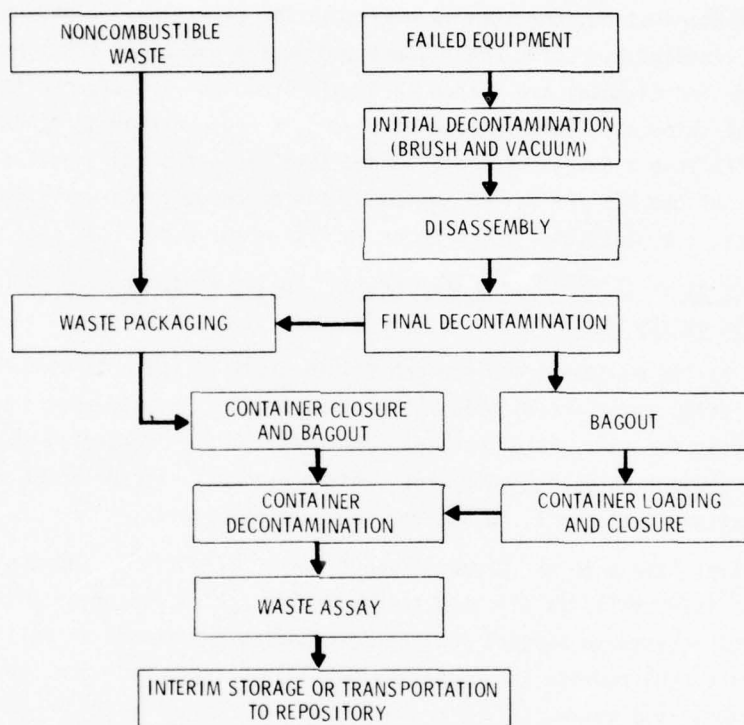


FIGURE 4.3.2. Flow Diagram for Failed Equipment and Noncombustible Waste Treatment at the MOX FFP

TABLE 4.3.12. Description of Packages of Treated Failed Equipment and Noncombustible Waste at the MOX FFP

Waste by Surface Dose Class, R/hr	Volume, ^(a) m ³ /yr	Density, kg/m ³	Volume Ratio ^(a) Treated/Untreated	Containers/yr		Radioactivity Factor ^(d)
				Drums ^(b)	Boxes ^(c)	
Noncombustible trash <0.2	82	250	1.0	394	--	1.0
Failed equipment <0.2	82	1000	1.0	--	20	0.05

a. Treated volume based on container volume.

b. 55-gal drums (0.208 m³).

c. 1.2 x 1.8 x 1.8 m (4.08 m³).

d. Radioactivity in packages, fraction of corresponding input (Table 4.3.11).

Removal of large equipment from process cells may require personnel entering the cell area. In this case, special protective clothing is provided, and equipment is dismantled within the cell and bagged out for transfer to the decontamination room for cleanup.

The decontamination and packaging area consists of decontamination gloveboxes and waste compaction stations. The decontamination gloveboxes are lined with stainless steel. Externally-controllable steam cleaning and high pressure water are available. A sump is used to collect all liquids, which are filtered and reused or sent to recovery.

Following decontamination, the item is available for packaging. Light, bulky items are compacted using a standard hydraulic ram. Compacted wastes and other scrap material of limited size that are ready for disposal are loaded in 55-gal drums and transferred to the storage area to await final shipment. Large pieces of equipment and parts of gloveboxes which will not conveniently fit into a 55-gal drum are loaded into canisters and transferred to the storage area. All of the MOX FFP failed equipment and noncombustible waste is classified as low-level TRU waste, i.e. less than 200 mrem/hr surface dose rate.

4.3.2.4 Description of Facilities for Treating Failed Equipment and Noncombustible Waste at the MOX FFP

Treatment of failed equipment and noncombustible waste at the reference MOX FFP is carried out in multifunctional areas used for general facility maintenance and waste management. The facilities for this waste treatment are specifically located in the pellet/rod production areas, production maintenance area, and in basement storage areas of the MOX FFP and are enclosed within Category 1, reinforced concrete structures.

These facilities have a total volume of about 204 m^3 (7200 ft^3). Approximately 45% of this volume, 91 m^3 (3200 ft^3), is allotted to processing failed equipment and noncombustible trash. The balance is used to support routine maintenance operations as well as for treating liquid waste. Space requirements for packaging are 105 m^3 (3700 ft^3) and 566 m^3 ($20,000 \text{ ft}^3$) for storing noncombustible waste.

Major Equipment Descriptions. Equipment used for the decontamination, disassembly, and packaging of MOX failed equipment includes saws, shears, compactors, decontamination tanks, and spray nozzles.

4.3.2.5 Operating and Maintenance Requirements for Treating Failed Equipment and Noncombustible Waste at the MOX FFP

Treatment of failed equipment and noncombustible trash at a MOX plant are part of routine, intermittent maintenance and housecleaning tasks conducted during normal plant operations. Since treatment equipment is also used for general plant purposes, it will be maintained according to procedures given for MOX FFP equipment in Section 3.2.4.

To control secondary wastes and contamination spread, all MOX FFP failed equipment and noncombustible waste is treated in a glovebox or cell. Removal of process residues and nominal decontamination reduce the direct radiation from failed equipment. Noncombustible

wastes generated within MOX facilities, however, are considered here to be always contaminated with transuranics. (This may be an overly conservative assumption.) Such wastes require special handling techniques to assure containment at all times to avoid the possibility of plutonium ingestion or inhalation by operating personnel. Techniques and technology for handling these wastes have been well developed in government-owned plants that routinely process plutonium on a production basis.⁽³⁾ Strict control of airflows and surface contamination help to insure safe working conditions.

Staffing. Personnel will not be assigned specifically to performance of failed equipment and noncombustible waste treatment functions, but individuals will spend fractions of their working hours on these tasks as noted in Table 4.3.13.

TABLE 4.3.13. Staffing Requirements for MOX FFP Failed Equipment and Noncombustible Waste Treatment

<u>Job Description</u>	<u>Personnel Required, man-yr/yr</u>
Operators	1.2
Radiation monitors	0.3
Maintenance craftsmen	1.2

Supplies and Utilities. Since the function of this task is not a process for which material and energy flows can be accurately determined, estimates of incremental needs for utilities and supplies were made. These estimates are given in Table 4.3.14.

TABLE 4.3.14. Supply and Utility Requirements for MOX FFP Failed Equipment and Noncombustible Waste Treatment

<u>Supply or Utility</u>	<u>Use Rate</u>	<u>Annual Requirement</u>
Electricity	100 kW	300,000 kWh
Acetylene (for cutting torches)	0.5 kg/hr	50 kg

4.3.2.6 Secondary Radioactive Wastes for Failed Equipment and Noncombustible Waste Treatment at the MOX FFP

Estimates of secondary wastes from this treatment task are listed in Table 4.3.15.

4.3.2.7 Emissions from Failed Equipment and Noncombustible Waste Treatment at the MOX FFP

Estimated emissions for this treatment task are given in Table 4.3.16.

TABLE 4.3.15. Secondary Radioactive Wastes for MOX FFP Failed Equipment and Noncombustible Waste Treatment

Description	Volume, m ³ /yr	Radioactivity Factor
Combustible and compactable waste	4	$1 \times 10^{-6(a)}$
Wet waste	1.6	$0.95^{(b)}$
Failed equipment	0.2	$1 \times 10^{-4(a)}$

- a. Fraction of total input activity (Table 4.3.11) in secondary wastes.
 b. Fraction of input activity on failed equipment (Table 4.3.11) in secondary wastes.

TABLE 4.3.16. Emissions from Mixed Oxide Fuel Fabrication Plant Failed Equipment and Noncombustible Waste Treatment

Emissions	Descriptions	Annual Quantity	Radioactivity Release Factor to Atmosphere
Gaseous	Ventilation air	$1 \times 10^8 \text{ m}^3$	$1 \times 10^{-15(a)}$
	Vaporized excess water	$3.8 \times 10^3 \text{ kg}$	$2 \times 10^{-9(b)}$
	Minor accident integrated annual release		None identified

- a. Fraction of input activity on noncombustible trash (Table 4.3.11) released to atmosphere. Includes DF from main plant APS. Released over 300 days/yr.
 b. Fraction of input activity on failed equipment (Table 4.3.11) released to atmosphere via waste concentrator and excess water vaporizer. Released over 300 days/yr.

4.3.2.8 Decommissioning Considerations for Facilities for Treating Failed Equipment and Noncombustible Waste at the MOX FFP

The failed equipment treatment facilities have no special impact on the final decontamination and decommissioning operation of the MOX plant. The treatment facilities will have the same life as the main plant and may be used for treatment of excess processing equipment during the decommissioning operation.

4.3.2.9 Postulated Accidents for Failed Equipment and Noncombustible Waste Treatment at the MOX FFP

The usual type of accidents associated with maintenance operations is expected in disassembly and packaging equipment for offsite shipment. The reference facilities for handling noncombustible wastes are designed to contain any releases resulting from accidents. Accident scenarios for this task are the same as those presented in Section 4.3.1.9.

4.3.2.10 Costs for Failed Equipment and Noncombustible Waste Treatment at the MOX FFP

Estimates of capital, operating and levelized unit costs are presented in mid-year 1976 dollars. A complete description of the cost estimate bases, assumptions and definitions is given in Section 3.8.

Capital Costs. The capital cost estimate for these facilities is shown in Table 4.3.17. Few of the areas in the MOX FFP can be identified as exclusively for treatment of failed equipment and noncombustible waste since these facilities are also used for normal maintenance and other waste management operations. Because the inclusion of such waste treatment functions may increase the MOX FFP facility sizes and capacities, however, a part of the basic cost is charged to the treatment of failed equipment and noncombustible waste. The proportion of the cost that is charged is based on the assumption that the waste treatment would require additional space and sharing of equipment in the dual-function facilities.

TABLE 4.3.17. Capital Cost Estimate for Facilities for MOX FFP Failed Equipment and Noncombustible Waste Treatment

Cost Element	1000s Man-hours		Costs 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		3	1220	40	1260
Buildings and structures		14	230	160	390
Bulk materials		3	150	40	190
Site improvements		—	—	—	—
Subtotal of direct site construction costs		20	1600	240	1840
Indirect site construction costs	5	5	90	120	210
Total field cost	5	25	1690	360	2050
Architect-engineer services					400
Subtotal					2450
Owner's cost					750
Total facility cost					3200
Estimated accuracy range					±50%

The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation with the exception of working capital and the specific exclusions stated below.

The accuracy range reflects uncertainties in the engineering scope required and in the pricing and quantities for labor, materials, and equipment. Because of the difficulties in estimating the quantities of failed equipment and noncombustible trash, the proportion of the waste treatment system which is charged to the handling of such wastes is not well defined.

The lack of a well-defined physical interface between the facilities for the reference waste treatment and the facilities designed for plant maintenance and routine waste handling also contributes to estimate uncertainty. A contingency covering these and similar factors has been included in the base estimate. With the contingency included, there is an approximately equal likelihood of the indicated cost overrun or underrun.

Operating Costs. The methodology for estimating operating costs is the same as discussed in Section 4.3.1.10. Table 4.3.18 summarizes the operating costs.

TABLE 4.3.18. Operating Cost Estimate for
MOX FFP Failed Equipment and
Noncombustible Waste Treatment

<u>Cost Element</u>	<u>Annual Costs, \$1000s</u>
Direct labor	120
Process materials	16
Utilities	6
Maintenance materials	40
Overhead	68
Miscellaneous	10
Total	260 +50% -25%

Levelized Unit Costs. The levelized unit cost, including levelized capital and operating costs, is shown in Table 4.3.19. The unit cost calculation assumes private ownership of the facilities and a 15-yr economic life.

TABLE 4.3.19. Levelized Unit Cost Estimate
for MOX FFP Failed Equipment
and Noncombustible Waste Treatment

<u>Cost Element</u>	<u>Unit Cost, \$/kg HM</u>
Levelized capital charge	2.00
Levelized operating charge	.50
Levelized total unit cost	2.50 ±50%

4.3.2.11 Construction Requirements for Facilities for Failed Equipment and Noncombustible Waste Treatment at the MOX FFP

As with the FRP, MOX FFP construction activities and requirements may have some impact on the environment and economy of the surrounding area. The information that follows provides a basis for evaluating any impact specifically attributable to the inclusion of failed equipment and noncombustible waste treatment functions in the designs for equipment maintenance and solid waste handling facilities at the reference MOX FFP. Such an impact is determined by charging

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a percentage of the total impact of the MOX FFP to the processing of failed equipment and non-combustible waste. Any impacts due to facility operation have not been considered in compiling this information.

Project Schedules and Construction Manpower. The schedule for engineering, procurement and construction of the failed equipment and noncombustible waste treatment facilities is an integral factor in the overall schedule for the MOX FFP. This schedule is presented in Section 3.2.

The field labor force estimated for the construction of the failed equipment and non-combustible waste treatment facilities is tabulated below:

	Man-hours, 1000s
Manual field labor	25
Nonmanual field labor	<u>5</u>
Total field labor	30

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials and services provided at the site of the MOX FFP while onsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is as shown below:

	Costs, \$1000s
Onsite	500
Offsite	<u>2700</u>
Total	3200

Resources Committed. Land commitments for the failed equipment and noncombustible waste treatment facilities are included with those of the MOX FFP.

Water. Approximately 760 m^3 (0.2×10^6 gal) of water are required during the construction period.

Construction Materials. Construction materials committed to the facility are:

Concrete	610 m^3	(800 yd ³)
Steel	180 MT	(200 tons)
Copper	.9 MT	(1 ton)
Lumber	50 m^3	(20 MFBM)

Energy. Energy resources used during construction will be:

Propane	3.8 m^3	(1,000 gal)
Diesel fuel	38 m^3	(10,000 gal)
Gasoline	38 m^3	(10,000 gal)
Electricity		
Peak demand	80 kW	
Total consumption	25,000 kWh	

4.3.22

Transportation Requirements. No transportation requirements for the failed equipment and noncombustible waste treatment facilities have been identified beyond those for the MOX FFP.

4.3.2.12 Effects of Fuel Cycle Options

A MOX FFP will exist only for the option of uranium and plutonium recycle. No facility will be needed for the other two fuel cycle options.

4.3.3 Physical Protection and Safeguard Requirements for Failed Equipment and Other Noncombustible Waste Treatment Facilities

The attractiveness of this material for theft or sabotage would be extremely low. The bulk of the radioactivity would have been removed by washing or leaching with acids before this waste is packaged for disposal. The residual quantities of plutonium and other radioactive materials in the waste would be small and widely distributed over many internal and external surface areas. The concentrations of plutonium in such wastes, even from FRP and MOX fuel plants, would be too low to be a source of strategic material. Further, the radioactive material would not be readily dispersible in a manner hazardous to the public. Accessibility for sabotage would be somewhat further restricted because the material would be treated and stored in closely controlled facilities and would often be handled only with remote handling features.

Failed equipment and other noncombustible waste would be treated initially in a vital area. The required physical protection for vital areas would be sufficient for safeguarding this waste (see 3.9). When the waste is moved out of the vital area, the physical protection required for the remainder of the plant will safeguard this waste material.

REFERENCES FOR SECTION 4.3

1. Barnwell Nuclear Fuel Plant Separation Facility: Final Safety Analysis Report. USNRC Docket 50-332, Allied-Gulf Nuclear Services, Barnwell, SC, October 10, 1973.
2. Westinghouse Recycle Fuels Plant, License Application, Volume 2. Docket 70-1432-2, Westinghouse Electric Corporation, Nuclear Fuels Division, October 12, 1973.
3. Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle, ERDA-76-43, U.S. Energy Research and Development Administration, Washington DC, Vol. 2, Section 8, May 1976.

4.4 GENERAL TRASH AND COMBUSTIBLE WASTE TREATMENT

4.4 COMPACTABLE AND COMBUSTIBLE WASTES TREATMENT

This section discusses treatment processes for transuranic-contaminated compactable and combustible trash, ion exchange resins, and ventilation filters at the reference fuel reprocessing plant (FRP) and the reference mixed-oxide fuel fabrication plant (MOX FFP). Almost all nuclear facilities generate some contaminated combustible and/or compactable materials. The major share of these materials appear as general trash, which includes laboratory and cell wastes, and consists primarily of cloth, paper, wood, plastics, rubber, and small amounts of glass and metals generated during maintenance and general support activities. This material is generated in a variety of ways, such as in decontamination of equipment, packaging of materials, discard of contaminated protective clothing, and discard of contamination protection barriers. Ion exchange resins may be generated during uranium, plutonium, and extractant purification steps. Ventilation filters (roughing filters and HEPA filters) are used in nuclear facilities to remove suspended particles from process and contamination-zone ventilation air. These filters, made of wood or metal frames with glass fiber filter media, are discarded periodically when dust loading has limited the flow or radioactivity has exceeded specified limits.

Often FRP waste is contaminated with transuranium elements as well as fission products and thus is classified as transuranic (TRU) waste. Most of the mixed-oxide fuel fabrication plant waste, if appreciably contaminated at all, contains plutonium and is classified as TRU waste. These wastes are treated and/or packaged and shipped either to interim storage or directly to a repository for disposal.

Some wastes considered as TRU wastes in this document could possibly be treated instead as non-TRU wastes by implementation of appropriate segregation and/or assay methods. Such wastes include laboratory-generated trash at the UF_6 and PuO_2 facilities at the FRP and also MOX-FFP wastes originating before plutonium is added to the process. Assay procedures have been used at DOE facilities to reduce the volume of TRU wastes,⁽¹⁾ however, assay systems are not currently developed to analyze for very low transuranic levels in the presence of fission product interference. Therefore, all potentially TRU-contaminated wastes are classified as TRU wastes in this document.

The light water reactor (LWR) fuel reprocessor and the MOX FFP operator have several main alternatives for handling compactable and combustible trash. The four alternatives for handling such trash which have been used in the nuclear industry, but not necessarily by fuel reprocessors, are⁽²⁾: 1) no treatment other than packaging, 2) compaction, 3) sorting and shredding of the waste followed by immobilization in cement or other solid matrix, and 4) sorting and shredding (if needed) of the waste followed by incineration to convert the waste to a noncombustible residue. Of the above, alternative 1 has the advantage of minimum complexity; alternatives 3 and 4 both have the advantages of making the waste noncombustible (thereby reducing the fire hazards in interim storage in transportation, and in the final repository); alternatives 2 and 4 result in an appreciable volume reduction; and, alternative 4 produces an ash from which the actinides might be recovered if so desired. Chemical digestion is also being developed as a treatment process which reduces volume, makes the waste noncombustible, and is compatible with actinide recovery. Incineration and packaging without treatment are chosen for analysis here since they represent the extremes of complexity of operation

and benefits to be gained in terms of stabilization and volume reduction of most of the waste. Incineration was selected as the reference process for the baseline integrated waste management system because of the desirability of minimizing fire risks in storage facilities and in the final repository.

4.4.1 Incineration of Intermediate-Level Waste (ILW) at the Fuel Reprocessing Plant

For the conceptual system here, the combustible and compactable wastes at the FRP are separated, on the basis of activity level and source, into an intermediate-level waste (ILW) and a low-level waste (LLW) and burned in two separate incinerators. Although operation of two incinerators was selected as most efficient in the generic FRP, this may not be optimum for other plants. The incinerator for the ILW handles all of the general trash at the FRP that produces surface radiation dose rates greater than 200 mr/hr on 55-gal drums, the waste from the PuO_2 conversion facility, all filter frames from the FRP, all contaminated ion exchange resins, and all secondary combustible waste and filters produced by waste treatment operations sited at the FRP regardless of radiation levels. Some of this secondary waste has surface radiation dose rates below 200 mr/hr but this division of the waste allows for reasonable equalization of the waste quantities to the two incinerators.

Combustion is a time-honored method of reducing waste volume and rendering the residue chemically inert. Of all available technologies, incineration most effectively reduces the volume and eliminates the combustible waste. Incineration of combustible radioactive waste has been practiced for over 25 years by nations involved with nuclear technology. A list of incineration units and discussions of installation experiences are available from several sources.⁽²⁻⁷⁾ Various systems have reduced waste volume by factors of 20 to 50 depending on the process, the composition of the waste, and the waste density.

Historically, incinerators have exhibited a variety of problems ranging from incomplete combustion to clogged off-gas system components to excessive corrosion throughout the equipment. Recent technological advances have effectively eliminated most of these earlier system deficiencies.^(4,6,7) Combustion design improvements have been spurred by the need for more effective, reliable incinerators to meet stricter Federal, state, and local pollution control standards. Comparable advances have been made in off-gas equipment design. Programs are underway at present to develop improved incinerators specifically for treating radioactive combustible waste. Although there is considerable experience with incineration of low-level radioactive waste, there is as yet no experience in designing or remotely operating an incinerator for intermediate-level waste.⁽⁵⁻⁷⁾

4.4.1.1 ILW Incineration Alternatives at the FRP

The reference incineration process discussed here is based on two incinerators at the fuels reprocessing plant (one for ILW and one for LLW) and one at the mixed-oxide fuel fabrication plant. Other arrangements are viable and might be more economically attractive under some circumstances. One incinerator, with separate feed preparation lines for ILW and LLW, might be used at the FRP. Another alternative would be to incinerate only the LLW and to package the ILW without treatment, thereby avoiding the presently undemonstrated remote operation

4.4.3

of an incinerator with high gamma activity wastes. If the MOX FFP is close-coupled to the FRP, it would be logical to eliminate one incinerator and process MOX FFP wastes in the FRP LLW incinerator since the annual throughput of the MOX-FFP incinerator is relatively small.

Numerous types of furnaces are used for incineration.⁽²⁾ Incinerators are classified by various characteristics which have no common basis. For example, they are classified according to shape, such as open pit or multiple chamber; to amount of air used, such as controlled air or excess air; and to moving parts, such as rotary kiln or moving grate. The following types of incinerators have been used or are being designed or studied in the nuclear industry.^(2,8,9)

Excess-Air (Firebox) Incinerator. This single-chamber incinerator uses excess air, resulting in lower burning temperatures but higher fly ash carry-over than in modern controlled-air incinerators.

Molten-Salt Incinerator. Combustible waste is burned with air in molten sodium carbonate and sodium sulfate. Acidic gases and particulate matter are trapped in the molten salt, and small amounts of metals and glass are also dissolved. Corrosion is lowered in the off-gas system but salt particles in the off-gas and dissipation of heat may be problems.

Pyrolysis Incinerator. Waste is thermally decomposed in an oxygen-deficient atmosphere, yielding a combustible gas which is burned with excess air in a secondary chamber. Accurate control of the amount of air fed to the burning chambers is necessary for efficient operation; tars may plug the combustible gas line.

Vortex Incinerator. Finely ground waste is pneumatically fed to the incinerator with excess air introduced tangentially, giving a spiral burning pattern to the suspended waste as it passes through the incinerator. The high excess air velocity through the chamber causes a large fly ash carry-over, requiring large off-gas treatment capacity. This system produces a high burning rate.

Fluidized-Bed Incinerator. Shredded waste is introduced into a vertical, highly agitated, fluidized bed of inert material, giving a high combustion efficiency. Substitution of pelletized sodium carbonate for the inert bed material can provide in situ neutralization for acidic combustion products such as hydrogen chloride, permitting use of less expensive off-gas treatment construction materials.

Rotary-Kiln Incinerator. The rotating, tilted horizontal combustion chamber provides a tumbling action for improved combustion efficiency and for positive ash removal. Offsetting these advantages are the complicated mechanical drives and the need for effective seals for containment and combustion air control.

Moving-Grate Incinerator. A moving or rotating grate constantly moves the waste material, exposing new unburned material for combustion and providing continuous ash discharge. This system, with its internal moving parts, presents greater maintenance problems than other types of incinerators.

Controlled-Air Incinerator. Substoichiometric quantities of air are used in the primary combustion chamber, resulting in a nonturbulent combustion environment and minimizing the entrainment of fly ash. Products of partial oxidation and volatilization flow into a secondary heated combustion chamber where excess air provides complete combustion.

Controlled-air incineration, representing "state-of-the-art" industrial waste disposal technology,⁽⁶⁾ has been applied in literally hundreds of circumstances ranging from disposal of pathological waste to combustion of scrap rubber and plastics. Advantages of the controlled-air incinerator design include: low emission of particles from the incinerator, operational flexibility for accepting a wide variety of wastes, and ease of combustion rate control. It appears to be the best choice among incineration alternatives for this application.

Other concepts currently being developed under Department of Energy (DOE) sponsorship,⁽²⁾ such as acid digestion⁽¹⁰⁾ or the fluid-bed, the vortex, the molten-salt or the rotary-kiln incinerators, may demonstrate significant advantages over the controlled-air concept. However, a radioactive demonstration (α -radiation only) of a production-scaled, controlled-air system⁽²⁾ is approximately one year ahead of a similar demonstration for the alternative systems.

Reference Incinerator and Off-gas Treatment System. Controlled-air incineration, with a high-energy, aqueous off-gas treatment system followed by HEPA filtration, has been chosen as the reference process. Advantages of the high-energy, aqueous off-gas treatment system include, but are not limited to: operational flexibility for satisfactory attenuation of a wide range of gaseous and particle emissions from the incinerators, the highest efficiency particle cleanup system, and widely demonstrated technology. A disadvantage is the rather large volume of scrubbing solution produced. A scrub concentration step was included to reduce the volume.

Alternative off-gas treatment systems include dry particle removal systems, such as cyclone separators, electrostatic precipitators, bag filters, filter candles, sintered metal filters, sand filters, and HEPA filters. Although the dry systems do not produce a secondary liquid waste requiring treatment, the most efficient of the dry systems are subject to plugging and generally cannot remove acidic components of the off-gas. In some cases hybrid systems consisting of both wet and dry processes are used (wet scrubbers remove the acidic gases).

Although the chosen reference system includes concentration of the off-gas scrubbing solution to near saturation, other alternatives could result in greater volume reduction. For instance, since the sodium chloride content of the solution is the volume limiting factor, the solution could be evaporated to a dry salt, or nonchlorine-containing plastics could be substituted in the materials producing the waste.

In summary, the reference controlled-air incinerator and off-gas cleaning equipment are based on proven technology modified to meet radiological health and safety standards. Although the process is comprised of "off-the-shelf" components, the system performance has not been tested with any radioactive wastes. Therefore, the system described and the performance data represent current best estimates, subject to revisions based on demonstration tests. It should also be emphasized that an incineration process has not been demonstrated with intermediate-level wastes, so the behavior of some of the fission products such as iodine, ruthenium, and cesium are not certain. The estimated performance with regard to these elements is based on what is known of their chemical properties in similar chemical environments.

4.4.1.2 Design Basis for the ILW Incineration Facility at the FRP

The ILW incineration facility is associated with the operation of the reference 2000-MTHM fuel reprocessing plant. All supporting facilities and services are provided by the reprocessing plant.

This facility receives 1430 m³ of TRU combustible trash, 320 m³ of ventilation filters, and 16 m³ of degraded FRP extractant per year. The 1430 m³ of TRU combustible trash includes that portion of the combustible trash from the main FRP that has a reading of >200 mR/hr in 55-gal drums, all the combustible trash from the PuO₂ conversion facility, the combustible trash (secondary waste) produced by all the other waste treatment facilities directly associated with the FRP, and all the ion exchange resins used in processing radioactive solutions in the main plant. Since the last three groups of trash are included on the basis of source rather than on the basis of activity levels, 10% of the total waste to this facility is expected to have readings of <200 mR/hr in 55-gal drums. The 320 m³ represent the entire volume of ventilation filters produced at the FRP and associated facilities. Thus, the total volume of combustible waste to be incinerated is 1750 m³ per year prior to filter frame crushing and shredding. The sources, composition, and amounts of the waste treated by the facility are given in more detail in Table 4.4.1.

Other assumptions made in the design of the ILW incineration facility include:

- The incineration facility is designed to process the intermediate-level TRU waste in 3000 hours of incinerator operation per year. The facility also has the capacity to process all the non-TRU combustible waste generated at the FRP.
- The ILW incineration facility includes, in addition to the incinerator itself, a filter media punch-out and pelletizing subsystem, a feed preparation subsystem with sorting and shredding capability, a feed assay subsystem, an off-gas treatment subsystem including aqueous scrubbing, and a scrub solution concentrator.
- The scrub solution concentrator is designed to handle the scrub solution from both the ILW incineration facility and the LLW incineration facility, including scrub solution from the ILW incinerator produced by incineration of non-TRU waste.
- The incinerator and off-gas treatment train are designed with capability to process feeds consisting of 100% of any one of the major combustible general trash components (cellulosics, plastic, rubber).

TABLE 4.4.1. Combustible and Compactable TRU Waste to be Processed Through the ILW Incinerator at the Fuel Reprocessing Plant(a)

Source	Composition, wt%		Density, kg/m ³	Volume, m ³ /yr
Main plant combustible trash	Paper/rags	40	120	800
	PVC	20		
	Neoprene	11		
	Polyethylene	14		
	Latex	11		
	Wood	4		
Main plant ventilation filters	Wood	60	160	280
	Glass	40		
Main plant ion exchange resins	Polystyrene	50	720	10
	Water	50		
Main plant degraded extractant	TBP (vol%)	30	800	16
	Dodecane (vol%)	70		
PuO ₂ conversion facility combustible trash	Paper/rags	40	120	60
	PVC	20		
	Neoprene	11		
	Polyethylene	14		
	Latex	11		
	Wood	4		
PuO ₂ conversion facility ventilation filters	Metal	60	160	40
	Glass	40		
Secondary waste ^(b) combustible trash	Paper/rags	40	120	560
	PVC	20		
	Neoprene	11		
	Polyethylene	14		
	Latex	11		
	Wood	4		

a. Based on primary waste characterization Table 3.3.33 and secondary waste characterization Table 3.5.1.

b. Waste generated by all the waste treatment facilities associated with the FRP.

- The assay subsystem provides material balance for fissile materials in the process and prevents cross-contamination by other classes of waste.
- Both the incinerator ash and the concentrated scrubber solution are routed to the facilities for wet waste and particulate solids immobilization for further treatment, as described in Section 4.7.

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- All utilities required for an orderly process shutdown, such as cooling water, power, ventilation, and compressed gas for pneumatic process controls, are assured by back-up systems.
- The ILW incineration facility structure is designed to withstand design-basis natural phenomena, including earthquakes and tornadoes, and to prevent penetration by maximum credible fire and/or explosion.
- The cost calculations for ILW include incineration of non-TRU as well as TRU general trash from the FRP.

4.4.1.3 ILW Incinerator Process at the FRP

The primary purpose of the ILW incinerator is to receive and incinerate intermediate-level combustible waste generated in the FRP. The volume and annual radionuclide content of the waste to be received by the ILW incineration facility are shown in Table 4.4.2. The incineration process reduces the volume of waste and converts it to a noncombustible form. Also the incineration process produces an ash from which transuranic elements such as plutonium could presumably be recovered if economically or otherwise desirable. (Such recovery is not treated in this document.)

The selected controlled-air incinerator and off-gas cleaning equipment (based on proven technology modified to meet radiological health and safety standards) are comprised of "off-the-shelf" components. Since the system's performance has not been tested with radioactive waste, the system and the performance data represent current best estimates, subject to revisions based on demonstration tests.

The overall incineration system, shown in Figure 4.4.1, is designed to accept the wide range of waste compositions anticipated at the FRP. The treatment process can best be described in terms of its subsystems: feed preparation, assay, incinerator charging, incineration, ash collection, off-gas treatment, scrubbing solution recycle, scrubbing solution concentration and auxiliary utilities.

Feed Preparation. The function of the feed preparation subsystem is to make the waste stream compatible with the incinerator. Operations performed in the feed preparation cell include: waste receiving, which introduces packaged waste into the process stream; assaying for determination of fissile material content and for detection of incompatible materials; sorting, for removal of incompatible materials; pretreatment, including filter dismantling and filter media pelletizing and packaging, to alter the form of certain materials as dictated by incinerator requirements; and storage of prepared waste to provide surge capacity between the fluctuating throughput of the feed preparation line and the nearly constant feed requirement of the incinerator. Figure 4.4.2 is a flow diagram of the feed preparation subsystem; stream data for the subsystem are given in Table 4.4.3.

TABLE 4.4.2. Radionuclide Content of Wastes Treated in the ILW Incineration Facility at the Fuel Reprocessing Plant (a)

Source	Volume, m ³ /yr	Fission Product Content, Ci/yr									
		³ H	¹²⁹ I	⁹⁰ Sr + ⁹⁰ Y	⁹⁵ Zr + ⁹⁵ Nb	¹⁰⁶ Ru + ¹⁰⁶ Rh	¹³⁴ Cs + ¹³⁷ Cs + ¹³⁷ Ba	¹⁴⁴ Ce + ¹⁴⁴ Pr	All Other Fission Products		
Primary Waste											
Main plant combustible trash	800	0	0	2.4 × 10 ²	2.2 × 10 ¹	7.6 × 10 ²	6.0 × 10 ²	9.6 × 10 ²	2.0 × 10 ²		
Main plant ventilation filters	280	0	0	2.4 × 10 ³	2.2 × 10 ²	7.6 × 10 ³	6.0 × 10 ³	9.6 × 10 ³	2.0 × 10 ³		
Main plant ion exchange resins	10	0	1.4 × 10 ⁻¹	2.4 × 10 ⁻¹	2.2 × 10 ²	7.6 × 10 ³	6.0 × 10 ¹	9.6 × 10 ¹	2.0 × 10 ¹		
Main plant degraded extractant	16	0	7.0 × 10 ⁻³	2.4 × 10 ¹	2.2 × 10 ¹	7.6 × 10 ²	6.0 × 10 ¹	9.6 × 10 ¹	2.0 × 10 ¹		
PuO ₂ conversion facility combustible trash	60	0	0	0	0	0	0	0	0		
PuO ₂ conversion facility ventilation filters	40	0	0	0	0	0	0	0	0		
Secondary Waste											
Combustible trash	560	5.9 × 10 ⁻¹	7.0 × 10 ⁻⁴	4.8 × 10 ¹	4.4 × 10 ⁰	1.5 × 10 ²	1.2 × 10 ²	1.9 × 10 ²	4.0 × 10 ¹		
TOTAL	1766	5.9 × 10 ⁻¹	1.4 × 10 ⁻¹	2.7 × 10 ³	4.9 × 10 ²	1.7 × 10 ⁴	6.8 × 10 ³	1.1 × 10 ⁴	2.3 × 10 ³		
Activation Products, Ci/yr											
		Actinide Content, Ci/yr			Activation Products, Ci/yr						
		²³⁹ Pu	²⁴¹ Pu	Other Plutonium	²⁴² Cm + ²⁴⁴ Cm	All Other Actinides	⁵⁵ Fe	⁶⁰ Co	⁹⁵ Zr + ⁹⁵ Nb	Other	
Main plant combustible trash	7.2 × 10 ⁻¹	3.5 × 10 ²	1.2 × 10 ¹	3.4 × 10 ¹	2.0	0	0	0	0		
Main plant ventilation filters	7.2	3.5 × 10 ³	1.2 × 10 ²	3.4 × 10 ²	2.0 × 10 ¹	0	0	0	0		
Main plant ion exchange resins	7.2	3.5 × 10 ³	1.2 × 10 ²	3.4	2.1 × 10 ^{-1(b)}	0	0	0	0		
Main plant degraded extractant	7.2	3.5 × 10 ⁴	1.2 × 10 ³	3.4 × 10 ¹	2.0	0	0	0	0		
PuO ₂ conversion facility combustible trash	3.6 × 10 ²	1.8 × 10 ⁵	6.2 × 10 ³			0	0	0	0		
PuO ₂ conversion facility ventilation filters	1.4 × 10 ³	7.0 × 10 ⁵	2.5 × 10 ⁴			0	0	0	0		
Secondary Waste											
Combustible trash	5 × 10 ⁻³	2.5 × 10 ⁰	3.4 × 10 ⁻²	6.8 × 10 ⁰	3.6 × 10 ⁻¹	8.2	8.2	3.4 × 10 ⁻¹	8.0		
TOTAL	1.8 × 10 ³	9.2 × 10 ⁵	3.3 × 10 ⁴	4.2 × 10 ²	2.5 × 10 ¹	8.2	8.2	3.4 × 10 ⁻¹	8.0		

a. Based on waste characterization Table 3.3.33 and secondary waste Table 3.5.1, assuming uranium and plutonium recycle, 2000 MTHM/yr reprocessed 1.5 years out of reactor

b. Includes 1.1 x 10⁻¹ Ci/yr of uranium.

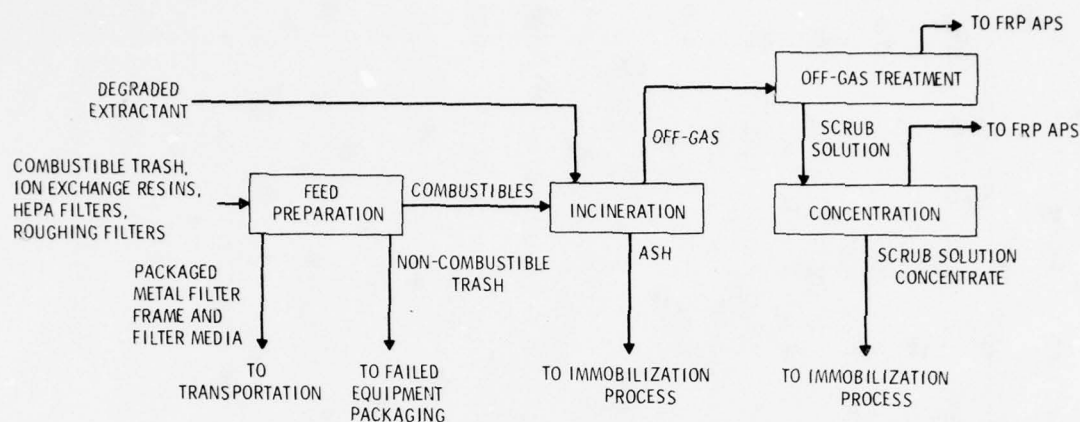


FIGURE 4.4.1. Process Flow Diagram for the Fuel Reprocessing Plant ILW Incineration Facility

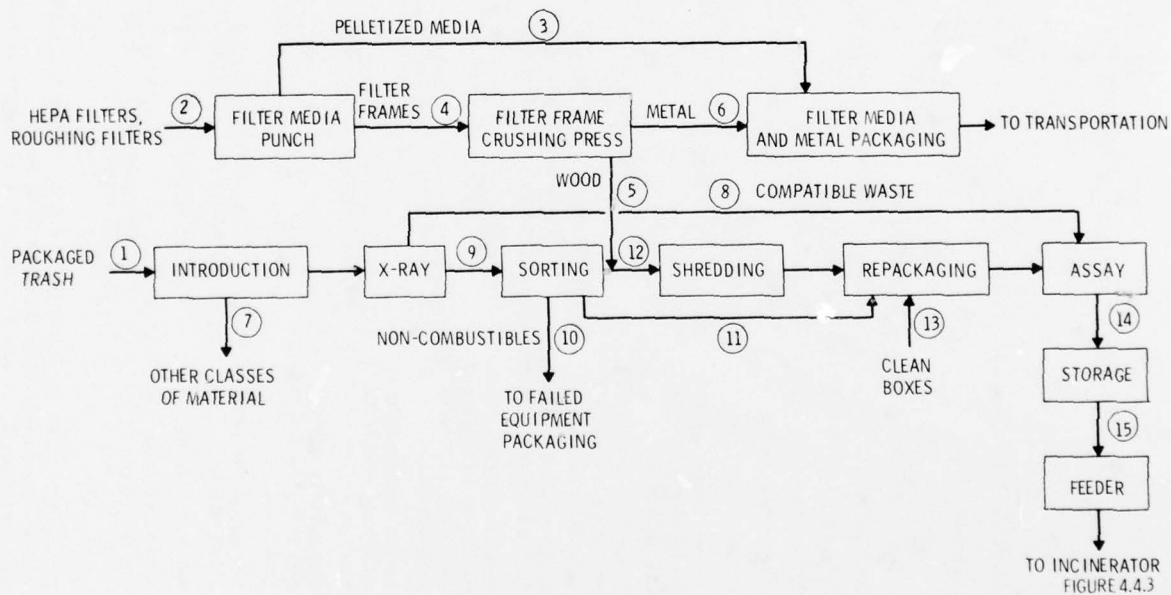


FIGURE 4.4.2. Feed Preparation Subsystem Flow Diagram for Fuel Reprocessing Plant ILW Incineration Facility (Circled numbers refer to the stream numbers given in Table 4.4.3.)

TABLE 4.4.3. Feed Preparation Stream Flow Data for the Fuel Reprocessing Plant ILW Incineration Facility

Stream Number	Description	Rate (b)	Radioactivity Fraction (a)							Activation Products
			³ H	¹²⁹ I	Zr, Nb Ru, Rh	All Other Fission Products	U	Pu	All Other Actinides	
1(c)	Packaged waste:									
	General trash	170,000 kg/yr	1.0	0.005	0.054	0.11	0.05	0.19	0.10	1.0
2(c)	Ion exchange resins	7,000 kg/yr	0	0.95	0.45	0.01	0.45	0.004	0.008	0
3	Ventilation filters	51,000 kg/yr	0	0	0.45	0.87	0.45	0.77	0.81	0
4	Pelletized filter media	20,000 kg/yr	0	0	0.45	0.87	0.45	0.77	0.81	0
5	Filter frames	31,000 kg/yr	0	0	0.009	0.018	0.009	0.015	0.016	0
6	Filter frame wood	27,000 kg/yr	0	0	0.009	0.018	0.009	8x10 ⁻⁵	0.016	0
7	Filter frame metal	4,000 kg/yr	0	0	0	0	0	0	0	0
8	Other classes of materials (included for completeness)	0	0	0	0	0	0	0	0	0
9	Compatible waste (75% of general trash and ion exchange resins)	135,000 kg/yr	0.75	0.95	0.45	0.088	0.45	0.12	0.08	0.75
10	Waste requiring sorting (25% of general trash)	38,000 kg/yr	0.25	0.001	0.014	0.026	0.014	0.05	0.024	0.25
11	Noncombustibles for packaging with failed equipment (included for completeness)	0	0	0	0	0	0	0	0	0
12	Sorted combustible waste not requiring feed shredding	20,000 kg/yr	0	0	0.006	0.012	0.006	0.023	0.01	0
13	Combustible waste requiring feed shredding	49,000 kg/yr	0	0	0.016	0.032	0.016	0.023	0.03	0
14	New boxes for repackaging waste	5,100 boxes/yr	0	0	0	0	0	0	0	0
15	Waste to storage	204,000 kg/yr	1.0	0.95	0.45	0.13	0.45	0.20	0.12	1.0
	Solid waste to incinerator	68 kg/hr (204,000 kg/yr)	1.0	0.95	0.45	0.13	0.45	0.20	0.12	1.0

a. Fraction of the total nuclide (Table 4.4.2) in the indicated stream

b. Incinerator is actually only operated 3000 hr/yr

c. The sum of streams 1, 2, and 17 (Table 4.4.4) comprises the input to the facility.

Incoming trash arrives sealed in plastic bags contained in sealed 30 x 30 x 61 cm (1 x 1 x 2 ft) cardboard boxes, which are then transported by pallet truck in shielded 30-gal drums to the process location. Boxes are loaded individually into the cell. Waste packages are placed on the synchronous conveyor for transport through an air lock past a flash x-ray system that is modified to compensate for the presence of gamma radiation.^(11,12) An x-ray screen (similar to airport security systems) displays any high-density materials that are not compatible with the incineration process.

Following x-ray scanning, packages containing compatible materials only (about 75% of the boxes) are placed on a conveyor for transport to the storage area. Other packages enter the sorting area where noncombustibles and high-density combustibles are removed. Noncombustibles are repackaged for removal from the cell; high-density combustible materials are shredded. A weir arrangement separates the sorting from the shredding area to prevent the entry of noncombustible material into the incinerator. A small home-type compactor, developing a ram force of 3000 lbs, is used to compress shredded combustibles for more efficient storage.

Since many filters, especially the widely used 61 x 61 x 30 cm (2 x 2 x 1 ft) HEPAs, are not easily processed, a special filter media punch-out system is under development at the DOE Rocky Flats Plant.⁽¹³⁾ This system consists of a hydraulically operated punch, rams, and an extruding die which compresses the punched-out filter media. The main hydraulic cylinder and punch-out platen, delivering 9,000 to 14,000 kg (20,000 to 30,000 lbs) of force, is used to separate the filter from the frame and extrude the media through a pelletizing die. Once the filter media are removed, the frames are flattened by a frame crushing press. Resulting wood is then shredded for incineration, and crushed metal frames are packaged for disposal. Pelletized media (in plastic bags) are packaged in 55-gal drums with 90-mil polyethylene liners⁽¹⁴⁾ along with the crushed metal filter frames.

Because of the high contamination levels that may be present on filters and the consequently high amounts of contaminated dust that may be generated during the media punch-out operations, the filter punch-out and frame-crushing presses are operated in a separate cell connected to the feed preparation cell. Negative air pressure is maintained with respect to the process area. The exhaust (roughly 2.8 m³/min or 100 ft³/min) is passed through a separate HEPA filter before being combined with the rest of the feed preparation system ventilation air.

The combustible waste from the sorting and shredding operations is repackaged and transported to the storage area. The storage area provides materials holdup adequate for approximately 1 hour of incinerator operation and is connected to the feed introduction subsystem.

Assay. The assay subsystem provides a material balance for fissile materials in the incineration process and prevents cross-contamination of the process by other classes of materials (scrap, low-gamma). Although the physical components of the subsystem are widely separated, the data collection, processing, and display are centralized at a mini-computer.

Incoming packages are assayed in the assay and load-out cell on a translating-rotating table.⁽¹⁵⁾ Ash is assayed in the collection hopper before packaging. Scrubbing solution is analyzed before transfer to the liquid treatment area.

These assay systems are not currently available for fission-product contaminated waste. The package assay system, adequate for weapons-grade plutonium, must be suitably modified. However, an assay system suitable for fission-product contaminated waste appears feasible and would probably be based on neutron counting rather than on gamma counting. Assay of the ash within the hopper and of the scrub solution stream requires development. As an alternative, the ash and scrub solution could be sampled and chemically analyzed.

Incinerator Charging. An incinerator charging subsystem transports waste from the holdup location in the feed preparation cell to the incinerator. Ram feeding has proved the most consistently reliable way to load incinerators. A ram feeder, structurally similar to a horizontal piston, forces waste packages past the guillotine doorway into the lower incinerator chamber. The modified, commercially-available ram feeder is chain driven with all moving components accessible. Combing teeth, located at the bottom of the ram, are used to counteract jamming, but should the ram overload, an automatic sensor reverses its direction and recycles it to clear the jam. The ram face is protected by a flame sensor and fire control system in case flaming material adheres to the ram face and is withdrawn from the lower incinerator chamber.

A variety of methods are available for loading waste packages from the storage area into the ram feeder. One method allows use of a simple slide for loading by locating the ram feeder on a lower level than the feed storage area. The method chosen here for the ILW incinerator makes use of a power manipulator to load the ram feeder directly. The pressure in the ram loading chamber is equalized with the incinerator, and, on demand, the packages are loaded into the lower incinerator chamber.

Incineration and Ash Collection. The incineration and ash collection flow diagram and stream data are shown in Figure 4.4.3 and Table 4.4.4, respectively. The controlled-air incinerator is a conventional dual-chamber design equipped with propane burners for supplemental heating. The incinerator design permits control of the quantity and location of combustion air supplied to the unit. By regulating the amount of air admitted to the primary chamber to near stoichiometric quantities, air velocity through the burning waste and ash is held low enough to avoid excessive particle entrainment. Partial combustion products from the primary chamber are oxidized at a higher temperature, under excess air conditions, in the secondary chamber.

The degraded extractant is fed (by atomization) to the high-temperature excess-oxygen secondary chamber. Under these conditions, it is completely burned. There is a disadvantage to this routing since essentially all of the extractant activity fed in this manner can be expected to end up in the off-gas. This increases the off-gas activity considerably. Since a decontamination factor (DF) of 250 is expected for nonvolatile elements across the primary chamber, an alternative may be to feed the small quantities of degraded extractant directly onto the solid waste being burned in the primary chamber and thus realize this additional DF.

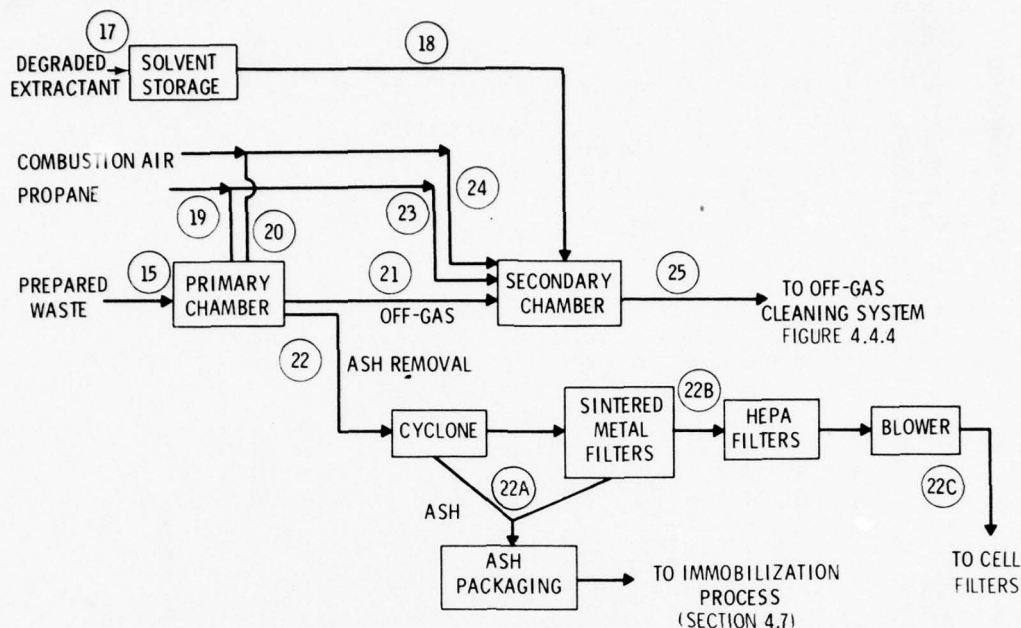


FIGURE 4.4.3. Incineration and Ash Collection for Fuel Reprocessing Plant ILW Incineration Facility (Circled numbers refer to stream numbers in Table 4.4.4.)

However, if this is done, problems with complete combustion and ash removal might occur. Another advantage for degraded extractant feeding to the primary chamber, which does not have excess oxygen, is that a ruthenium volatilization factor of 10^{-3} or less is likely, whereas in the higher temperature, excess-oxygen secondary chamber, 10% volatilization of ruthenium is likely. However, in either case volatile ruthenium species are expected to revert back to particulate material upon cooling of the off-gas stream⁽¹⁶⁾ and, thus, be efficiently removed in the off-gas filtration system.

The ash collection subsystem removes the combustion residue (ashes) from the incinerator and packages them for transport to the immobilization process. The ash are vacuumed manually from the lower incinerator chamber using manipulators and an extendable vacuum cleaner hose. They are transported by vacuum to the ash packaging cell where they are separated from the vacuum air stream by a high-efficiency cyclone and sintered-metal filters. The removed ash falls into a collection hopper. The vacuum is supplied by an induced-draft, positive-displacement blower. Upstream HEPA filters protect the blower from contamination. Air is discharged through the cell HEPA filtration system. The ash is assayed in the hopper and metered into shielded 55-gal drums for transport to the dispersible solids immobilization area.

Off-Gas Treatment. The high-energy aqueous off-gas conditioning system cleans the incinerator combustion gases. The process involves cooling the gases, removing particles, removing mineral acids, and lowering the dew point of the gas for final filtration. Figure 4.4.4 diagrams the off-gas treatment process; Table 4.4.5 gives the stream data.

TABLE 4.4.4. Incineration and Ash Collection Stream Flow Data for the Fuel Reprocessing Plant ILW Incinerator Facility

Stream Number	Description	Rate (b)	Radioactivity Fraction (a)						
			^3H	^{129}I	Zr, Nb, Ru, Rh	All Other Fission Products	U	Pu	All Other Actinides
15	Solid waste to incinerator	204,000 kg/yr	1.0	0.95	0.45	0.13	0.45	0.2	0.12
17(c)	Degraded extractant to storage	13,000 kg/yr	0	0.047	0.045	0.01	0.045	0.04	0.08
18	Degraded extractant to incinerator	0.07 kg/min	0	0.047	0.045	0.01	0.045	0.04	0.08
19	Primary chamber propane supply	0 - 1 m ³ /min	0	0	0	0	0	0	0
20	Primary chamber air supply	4.5 - 15 m ³ /min (STP)	0	0	0	0	0	0	0
21	Primary chamber off-gas	5.7 - 15 m ³ /min (STP)	1.0	0.95	0.002 4.5 x 10 ⁻⁴ (d)	5 x 10 ⁻⁴	0.002	7.7 x 10 ⁻⁴	5 x 10 ⁻⁴
22	Ash removal system (not operative during processing):								
22a	Ash	16,000 kg/yr		9.5 x 10 ⁻⁴	0.45	0.13	0.45	0.22	0.18
22b	Transport air	8.5 m ³ /min	---	---	---	---	---	---	---
22c	Filtered air	8.5 m ³ /min	---	2 x 10 ⁻¹⁵	4.5 x 10 ⁻¹³	1.3 x 10 ⁻¹³	4.5 x 10 ⁻¹³	2.2 x 10 ⁻¹³	1.8 x 10 ⁻¹³
23	Secondary chamber propane supply	0 - 1 m ³ /min	0	0	0	0	0	0	0
24	Secondary chamber air supply	1.4 - 15 m ³ /min (STP)	0	0	0	0	0	0	0
25	Incinerator off-gas	10 - 32 m ³ /min (STP)	1.0	.995	0.045 0.0045(d)	0.01	0.045	0.04	0.08

a. Fraction of the total nuclide (Table 4.4.2) in the indicated stream

b. Rates in units of minutes are instantaneous rates based on 3000 hours of incinerator operation per year

c. The sum of streams 1 and 2 (Table 4.4.3) and 17 comprises the input to the facility

d. Volatile Ru species only. See rest of listing for particulate Ru.

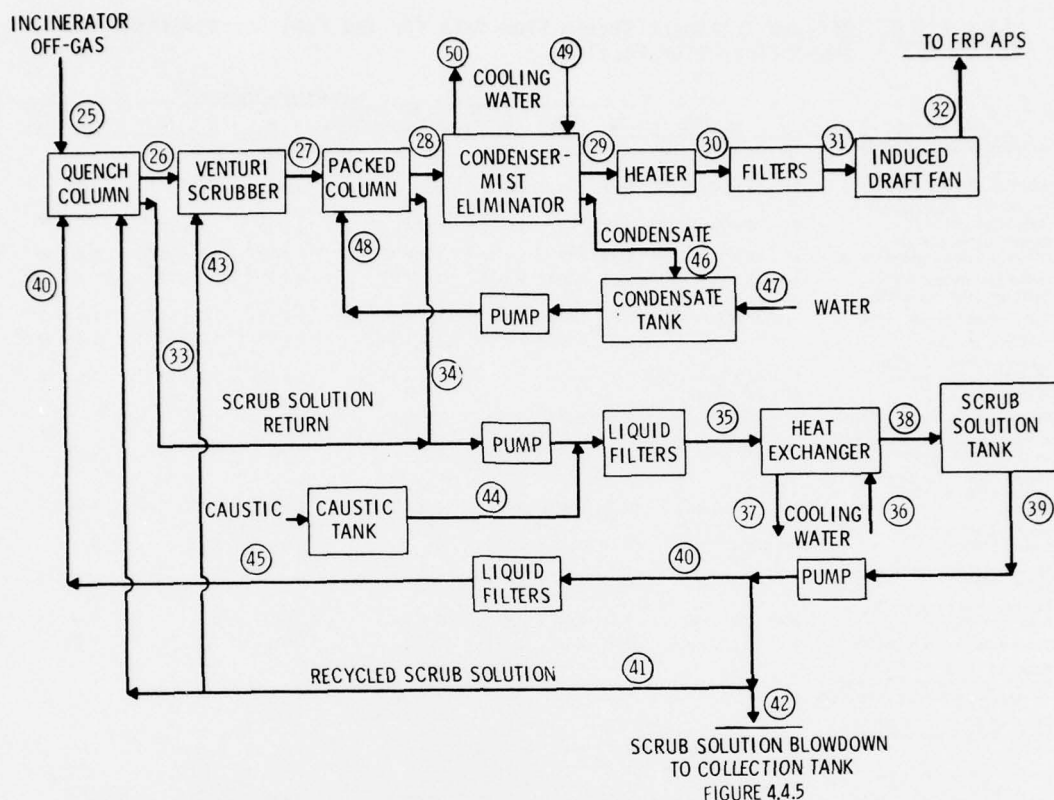


FIGURE 4.4.4. Off-gas Treatment Flow Diagram for the Fuel Reprocessing Plant ILW Incineration Facility (Circled numbers refer to stream numbers given in Table 4.4.5.)

The quench column cools combustion gases from 1400°C (2500°F) to 77°C by direct evaporation of recycled scrubbing solution. Approximately eight times the amount of scrub solution required for evaporative cooling is injected into the contacting section, which consists of a 25 cm (10-in.) ID pipe with a weir, three spray lances, and an exit nozzle. The weir keeps the refractory wall fully wetted; spray lances, located below the weir, atomize scrub solution for better gas-liquid contact. A separator de-entrains the quench liquid.

The variable-throat venturi scrubber, located between the quench column and packed column, removes up to 99 wt% of the off-gas particulate distribution shown in Table 4.4.6.

The packed column scrubber reduces the gas-phase hydrogen chloride by counter-current contact with condensate and/or fresh water. The condenser serves to lower the off-gas temperature from 65°C to 50°C. Because the stream is water-saturated before reaching the condenser, approximately 20 ℓ /min (5 gal/min) of condensate must be removed. The off-gas then passes through a mist eliminator to the reheater which superheats the off-gas to approximately 10°C above the saturation temperature to assure that any entrained liquid is vaporized and that condensation and attendant corrosion does not occur downstream in the HEPA filters or off-gas blowers. Two stage HEPA filtration, preceded by one roughing filter, is provided for final particle removal. The gas is then routed to the FRP atmospheric protection system (see Section 4.11) for final filtration and discharge via the FRP stack.

TABLE 4.4.5. Off-gas Treatment Stream Flow Data for the Fuel Reprocessing Plant
ILW Incineration Facility

Stream Number	Description	Rate (b)	Radioactivity Fraction (a)						
			³ H	¹²⁹ I	Zr, Nb Ru, Rh	All Other Fission Products	U	Pu	All Other Actinides
25	Incinerator off-gas (1100°C)	10 - 32 m ³ /min (STP)	1.0	0.995	0.045 0.005(c)	0.01	0.045	0.04	0.08
26	Quenched off-gas (77°C)	21 - 60 m ³ /min (STP)	0.57	0.52	0.045	0.01	0.045	0.04	0.08
27	Venturi scrubbed off-gas (particles removed)	21 - 60 m ³ /min (STP)	0.57	0.52	9 x 10 ⁻⁴	1.8 x 10 ⁻⁴	9 x 10 ⁻⁴	7.7 x 10 ⁻⁴	1.6 x 10 ⁻³
28	Packed column off-gas (mineral acids removed)(65°C)	21 - 60 m ³ /min (STP)	0.43	0.52	9 x 10 ⁻⁴	1.8 x 10 ⁻⁴	9 x 10 ⁻⁴	7.7 x 10 ⁻⁴	1.6 x 10 ⁻³
29	Condenser off-gas (50°C) (most of water removed)	11 - 32 m ³ /min (STP)	0.21	0.52	9 x 10 ⁻⁴	1.8 x 10 ⁻⁴	9 x 10 ⁻⁴	7.7 x 10 ⁻⁴	1.6 x 10 ⁻³
30	Superheated off-gas (60°C)	11 - 32 m ³ /min (STP)	0.21	0.52	9 x 10 ⁻⁴	1.8 x 10 ⁻⁴	9 x 10 ⁻⁴	7.7 x 10 ⁻⁴	1.6 x 10 ⁻³
31	Filtered off-gas		0.21	0.52	9 x 10 ⁻¹¹	1.8 x 10 ⁻¹¹	9 x 10 ⁻¹¹	7.7 x 10 ⁻¹¹	1.6 x 10 ⁻¹⁰
32	Cleaned off-gas to plant atmospheric protection system (APS)	11 - 32 m ³ /min (STP) (4 x 10 ⁶ m ³ /yr)	0.21	0.52	9 x 10 ⁻¹¹	1.8 x 10 ⁻¹¹	9 x 10 ⁻¹¹	7.7 x 10 ⁻¹¹	1.6 x 10 ⁻¹⁰
33	Excess quench liquid return	90 - 106 l/min	0.43	0.24	---	---	---	---	---
34	Venturi scrubber and packed column liquid return	87 - 132 l/min	0.36	0.24	0.045	0.01	0.045	0.04	0.08
35	Neutralized scrub solution return after particle removal	174 - 238 l/min	0.71	0.47	0.011	0.002	0.011	0.01	0.02
36	Scrub solution cooler, water supply (24°C)	795 l/min	0	0	0	0	0	0	0
37	Scrub solution cooler water return (32°C)	795 l/min	0	0	0	0	0	0	0
38	Cooled scrub solution to hold tank (32°C)	174 - 238 l/min	0.71	0.47	0.011	0.002	0.011	0.01	0.02
39	Scrub solution tank outlet	172 - 223 l/min	0.71	0.47	0.011	0.002	0.011	0.01	0.02
40	Recycled scrub solution to quench column wter (filtered to remove additional particles)	68 l/min	---	---	---	---	---	---	---
41	Recycled scrub solution to quench column and venturi scrubber	102 - 148 l/min	---	---	---	---	---	---	---
42	Scrub solution blowdown to concentrator collec- tion tank (32°C)	5.7 l/min (1.0 x 10 ⁶ l/yr)	0.71	0.47	0.011	0.002	0.011	0.01	0.02
43	Venturi solution	57 - 102 l/min	---	---	---	---	---	---	---
44	Caustic solution (20% NaOH) addition	0 - 3.8 l/min	0	0	0	0	0	0	0
45	Solid caustic and water		0	0	0	0	0	0	0
46	Condensate return	11 - 23 l/min	0.21	---	---	---	---	---	---
47	Scrubbing solution makeup water	2.8 - 30 l/min	0	0	0	0	0	0	0
48	Condensate recycle to packed column	30 l/min	0.21	---	---	---	---	---	---
49	Condenser cooling water supply (t _c)	570 l/min	0	0	0	0	0	0	0
50	Condenser cooling water return (t _c + 20°C)	570 l/min	0	0	0	0	0	0	0

a. Fraction of the total nuclide (Table 4.4.2) in the indicated stream

b. Rates in units of minutes are instantaneous rates based on 3000 hours of incinerator operation per year

c. Volatile Ru species only. See rest of listing for particulate Ru.

TABLE 4.4.6. A Typical Off-gas Particulate Size Distribution Which is 99% Removable by the Venturi Scrubber

<u>Particle Diameter, μm</u>	<u>wt%</u>
Greater than 10	10
5-10	20
2-5	40
1-2	20
0.5-1	10

Note: Specific gravity - 1.5;
particle loading - 0.23 g/m³

Scrubbing Solution Recycle. Scrubbing solution used in the off-gas cleaning subsystem is recycled to minimize liquid effluents. Recycled solution is filtered, cooled, and neutralized as shown in Figure 4.4.4. Table 4.4.5 includes data for the recycle operation.

Solution from the quench and packed columns is pumped through full-flow filters to remove suspended particles. The fluorocarbon-coated housings use polypropylene cartridge-type filters and are located in the feed preparation cell to facilitate filter changes. The spent cartridges are bagged and incinerated.

The filtered solution is cooled to 32°C (90°F) in a shell-and-tube heat exchanger equipped with graphite tubes. The operating pressure of the tube side is maintained below that of the coolant side to minimize the chance of coolant contamination.

Scrub solution is collected in a 3800- ℓ (1000-gal) receiver tank. To control acidity, 20% caustic solution is added to the solution; the addition rate is controlled by a pH sensor on the outlet of the tank. The caustic solution is held in a 1300- ℓ (350-gal) stainless steel tank. To control the salt content of the recycled solution, a 5.7- ℓ /min (1.5 gal/min) blowdown stream is drawn off. The recycled scrubbing solution is pumped from the tank to the venturi and the quench column.

Condensate from the condenser/mist eliminator module drains into a 1100- ℓ (300-gal), stainless steel condensate receiver tank. The level in this tank is maintained by the addition of fresh water. This solution, which is low in acid content, is pumped to the top of the packed column scrubber.

Scrubbing Solution Concentration. To reduce waste volume, the scrub solution must be concentrated prior to immobilization. A flow diagram of the concentration process is shown in Figure 4.4.5; stream data is given in Table 4.4.7. The concentrator is designed to have sufficient capacity for concentration of the scrub solution from incineration of both the TRU-ILW and TRU-LLW from the FRP (Section 4.4.2), as well as the solution generated by incineration of non-TRU waste at the FRP. Although these three scrub solutions are expected to be combined,

4.4.18

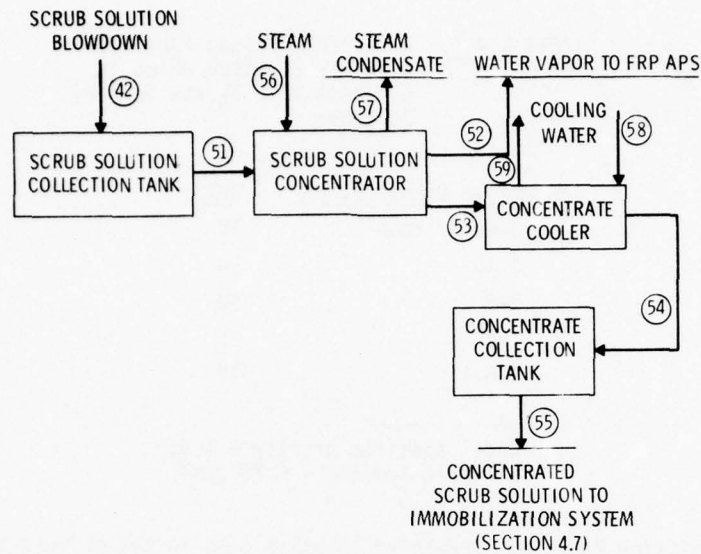


FIGURE 4.4.5. Scrub Solution Concentration Flow Diagram for the Fuel Reprocessing Plant ILW Incineration Facility (Circled numbers refer to stream numbers given in Table 4.4.7.)

TABLE 4.4.7. Scrub Solution Blowdown Concentration Stream Flow Data for the Fuel Reprocessing Plant ILW Incineration Facility

Stream Number	Description	Rate ^(b)	Radioactivity Fraction ^(a)						
			³ H	¹²⁹ I	Zr, Nb, Ru, Rh	All Other Fission Products	Pu	All Other Actinides	Activation Products
42	Scrub solution blowdown (32°C)	5.7 μ /min (1.0×10^6 μ /yr)	0.71	0.47	0.011	0.002	0.01	0.02	0.001
51	Concentrator feed	5.7 μ /min	0.71	0.47	0.011	0.002	0.01	0.02	0.001
52	Water vapor (to plant APS)	5.9 m ³ /min (STP) (1.1×10^6 m ³ /yr 8.5×10^5 kg/yr)	0.57	0.43	1.1×10^{-7}	2.2×10^{-8}	1×10^{-7}	8×10^{-8}	1×10^{-8}
53	Concentrator bottoms (~100°C)	0.9 μ /min	0.14	0.05	0.011	0.002	0.01	0.02	1×10^{-3}
54	Cooled concentrator bottoms (38°C)	0.9 μ /min	0.14	0.05	0.011	0.002	0.01	0.02	1×10^{-3}
55	Concentrated liquids to immobilization system	0.9 μ /min (1.5×10^5 μ /yr)	0.14	0.05	0.011	0.002	0.01	0.02	1×10^{-3}
56	Steam	6 kg/min (1.1×10^6 kg/yr)	0	0	0	0	0	0	0
57	Condensate return	6 kg/min	0	0	0	0	0	0	0
58	Cooling water (t_c)	3.4 μ /min	0	0	0	0	0	0	0
59	Cooling water return ($t_c + 15^\circ\text{C}$)	3.4 μ /min	0	0	0	0	0	0	0

a. Fraction of the total nuclide (Table 4.4.2) in the indicated stream

b. Rates in units of minutes are instantaneous rates based on 3000 hours of incinerator operation per year.

Figure 4.4.5 and Table 4.4.7 describe only the portion of the overall concentration flowsheet attributable to the scrub solution from incineration of transuranic ILW. This flowsheet is based (as is the rest of Section 4.4.1.3) on 3000 hours of operation per year.

The concentrate cooler for the concentrator bottoms cools the solution to 38°C, which is acceptable for solidification by the cementation process (Section 4.7). The water vapor from the concentrator is sent to the FRP atmospheric protection system (Section 4.11) where a DF of 10^4 for particulates is obtained.

Auxiliary Utilities. To allow an orderly process shutdown under abnormal conditions or during a utility failure, three back-up systems are required: electrical supply, cooling water supply, and a compressed nitrogen supply.

Two types of electrical back-up are needed: a floating battery and an auxiliary power generator. The floating battery back-up (5 kVA) is on-line at all times during operation to eliminate the momentary power interruption which would occur should switching from normal utility power supply to the auxiliary generator (300 kVA) be required. The momentary interruption must be avoided as it would cause process control relays to disengage. The auxiliary generator supplies power required by high-consumption process equipment such as pumps, blowers, heaters, and motors for normal process shutdown.

The incinerator exhaust is cooled by direct evaporation of scrubbing solution. Loss of this quench liquid would present an immediate threat to the integrity of the off-gas cleaning components. A two-hour supply of pressurized water (1700 l) is maintained for release to the quench column should the scrubbing solution recirculation pump fail.

A compressed nitrogen supply (2 cylinders) is kept on hand to supplement the normal instrument air supply should it be interrupted. This supply is required for the pneumatic process controls.

Many of these utility requirements are met by systems already required to support operations at the fuel reprocessing plant. Therefore, the back-up requirements of the incineration process represents a small increase in the size of the primary plant back-up system rather than a separate new system.

ILW Incineration Facility Products. The product of treating the ventilation filters shown in Table 4.4.1 in the ILW incineration facility is described in Table 4.4.8. The pelletized filter media and filter frame metal, packaged in 55-gal drums, are sent either to the interim storage facility or to a waste repository. Ash and concentrated scrubbing solution are also produced and sent to the immobilization facility for wet wastes and particulate solids for further treatment; these products are described as secondary wastes in Section 4.4.1.6.

4.4.1.4 Description of the ILW Incineration Facility at the FRP

Figure 4.4.6 shows the position of this facility in relation to the rest of the FRP and associated facilities. As indicated in this figure, the ILW incineration facility is located in a general trash and combustible waste treatment area attached to the FRP main process building. This area is also directly attached to the wet waste and particulate solids immobilization area (number 31 in Figure 4.4.6). This allows for direct transfer of solid combustible or combustible waste from the main FRP facility to the incineration facility, and

TABLE 4.4.8. Packaged Waste Leaving ILW Incineration Facility^(a)

Volume ^(b)	80 m ³ /yr
Density	300 kg/m ³
Volume Treated ^(b) Volume Untreated	0.25
55-gal drums/yr	400
Surface dose rate	<10 R/hr
Radioactivity as fraction of input: ^(c)	
Zr, Nb, Ru, Rh	0.45
Other fission products	0.89
Pu	0.0038
Other TRU	0.81

- a. Packaged waste comprised of pelletized filter media and frame metal. Other wastes are secondary wastes requiring further treatment (Table 4.4.12)
- b. Treated volume based on container volume
- c. Fraction of total input activity to the facility (Table 4.4.2).

for the transfer of ash and scrub solution concentrate from the incineration facility to the immobilization facility. Although the flowsheets and discussion in Section 4.4.1.3 indicate transfer of the ash from the incinerator to the immobilization facility in shielded 55-gal drums, pneumatic transfer of the ash directly to the immobilization facility as it is vacuumed from the incinerator might be preferable.

The reference ILW controlled-air incineration process is housed in a 30 x 22 m (96 x 71 ft) concrete walled area as seen in the floor plan and layout shown in Figure 4.4.7. The process area consists of a series of remote cells separated from each other by ventilation barriers. To control the spread of contamination, each subsystem is housed in a separate cell. The floors of the cells are lined with stainless steel pans which collect contaminated liquid from the process or decontamination washdowns and drain to a sump. Waste comes into the cells through the feed inspection cell and exits as ash from the ash packaging cell and as concentrated liquid scrub solution via a line to the immobilization facility. An exit for removing drummed noncombustibles is provided at the assay and noncombustible loadout cell. The operating area provides space for the process instrumentation and control system.

The ILW incineration facility is constructed of reinforced concrete to withstand design-basis natural phenomena, including earthquakes and tornadoes, and to prevent penetration by a maximum credible fire and/or explosion. The facility is designed to meet Category I structural requirements.⁽¹⁷⁾

Cells. The incineration cell is equipped with master-slave manipulators for maintenance of the ram feeder drive mechanism. A bridge-mounted power manipulator is provided for transfer of waste from the storage cell into the incinerator ram feeder. The upper and lower incinerator chambers can be removed through the top of the cell when required. The cell can be washed down to aid in decontamination prior to personnel entry.

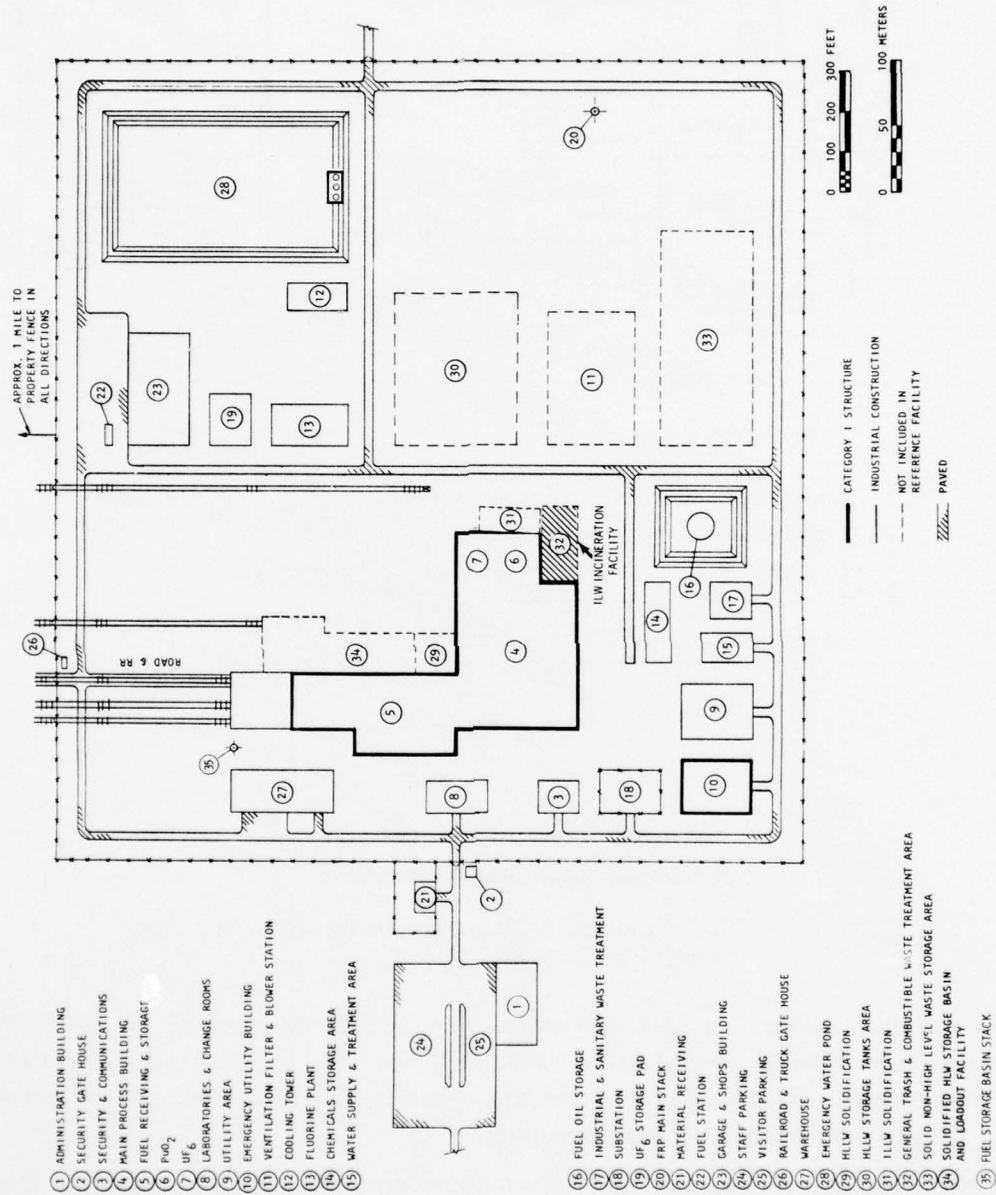


FIGURE 4.4.6. Approximate Location of ILW Incineration Facility Within the Fuel Reprocessing Plant

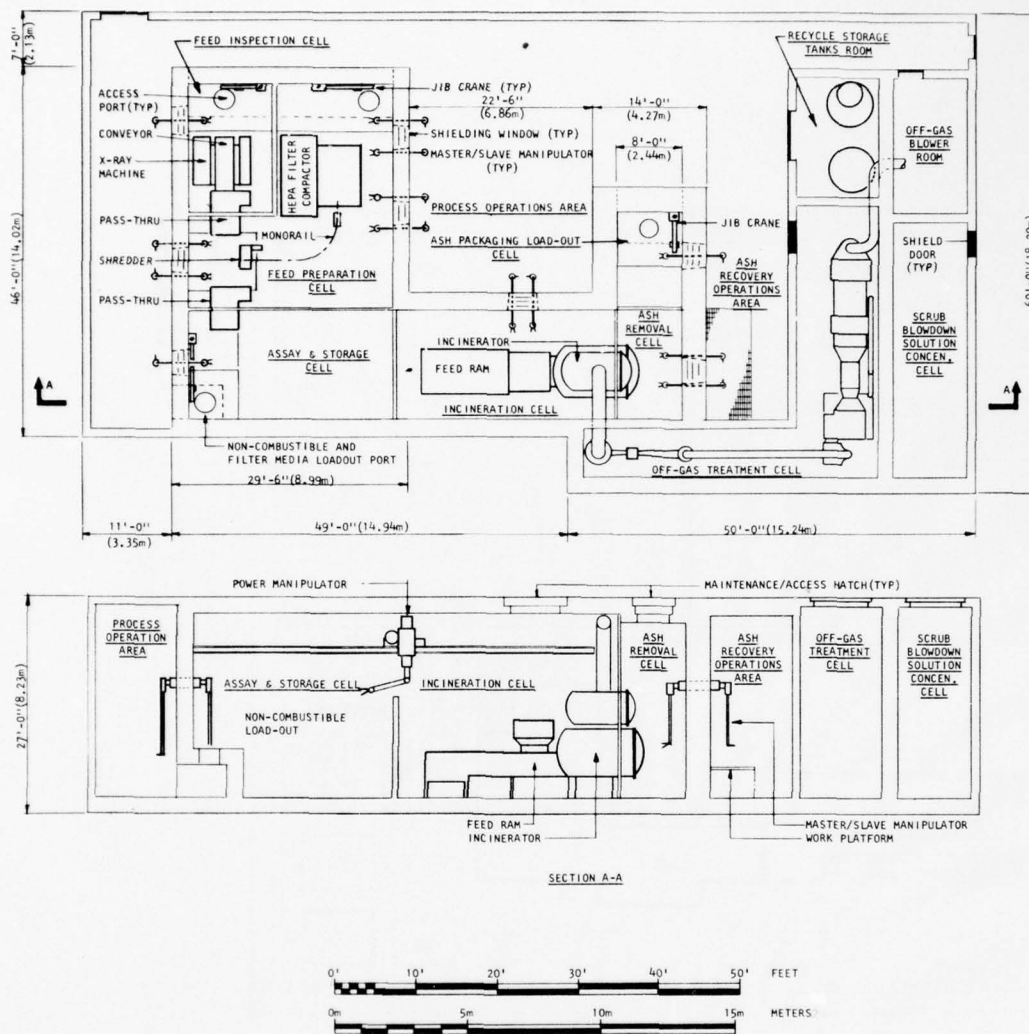


FIGURE 4.4.7. Fuel Reprocessing Plant ILW Incineration Facility, General Plan and Section A-A

The ash removal cell is equipped with manipulators to provide access to the inside of the two incinerator chambers through the ash removal doors. Ash is pneumatically removed from the lower chamber using manipulators and an extendable hose mechanism. Tramp noncombustibles can also be removed with the manipulators.

The ash packaging cell has a manipulator and a jib crane to operate and maintain the ash removal and packaging equipment. Shielding, remote operation, and maintenance capabilities are required because of the high concentration of radioisotopes in the ash.

The feed inspection, feed preparation, and storage cells have manipulators and overhead cranes and/or synchronous conveyers to perform the required operations, to move or replace equipment, and to transport packaged noncombustibles to the cell load-out facility.

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X-ray Scanner. The x-ray system used to detect high-density materials in the incoming waste is similar to that used in airport security systems.^(11,12) This equipment must be modified over that currently available to compensate for the gamma radiation emitted by the waste.

Filter Compactor. A filter media compactor is under development at the DOE Rocky Flats Plant.⁽¹³⁾ This system, shown in Figure 4.4.8, consists of hydraulically operated punch-out and pelletizing rams that separate the filter media from the frame and extrude the media through a pelletizing die. These rams develop up to about 14,000 kg (30,000 lb) of force. The frames are then crushed by a simple press, also shown in Figure 4.4.8. Minor modifications of this equipment would probably be made to improve the efficiency of remote operation.

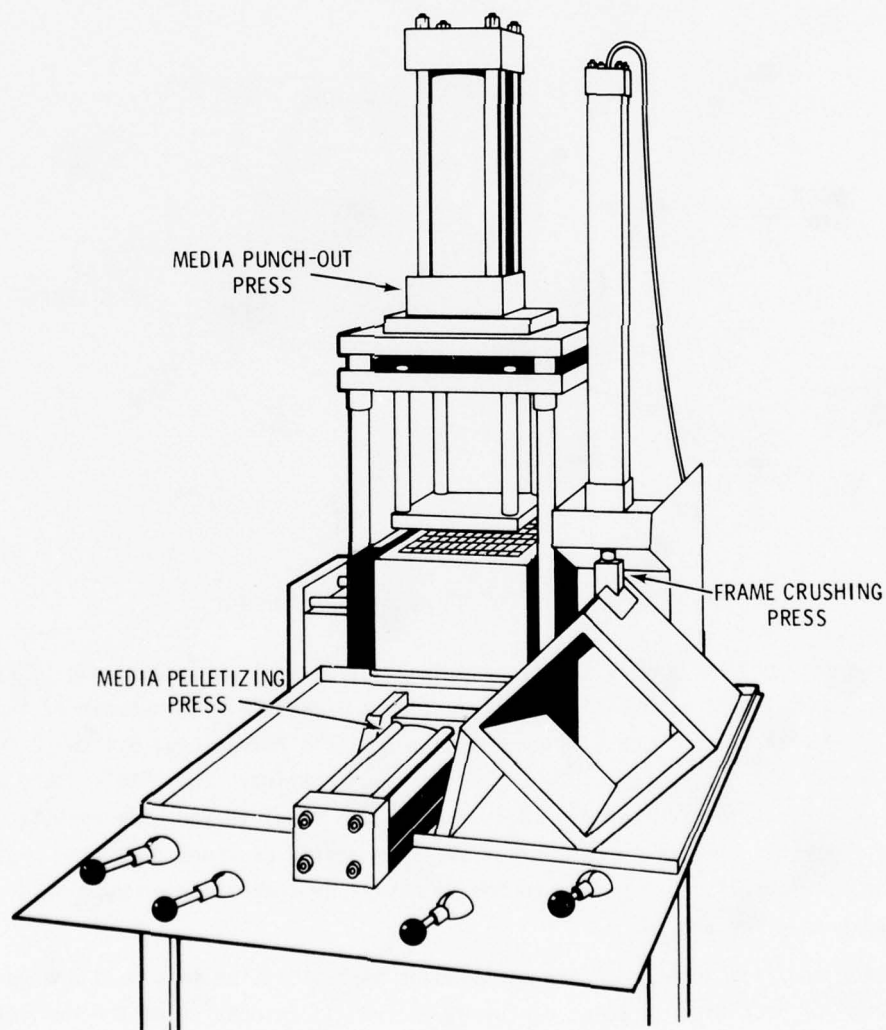


FIGURE 4.4.8. Filter Media Compactor

Feed Shredder. A conventional, low-speed shredder is capable of handling small pieces of wood and heavy paper or cardboard, such as stacks of computer cards.

Ram Feeder. A commercially available ram feeder is modified in such ways as necessary to increase the ease of remote maintenance.

Incinerator. The controlled-air incinerator, shown in Figure 4.4.9, is of a conventional, dual-chamber design, and is equipped with propane burners for supplemental heating. The incinerator design permits control of the quantity and location of combustion air supplied to the unit.

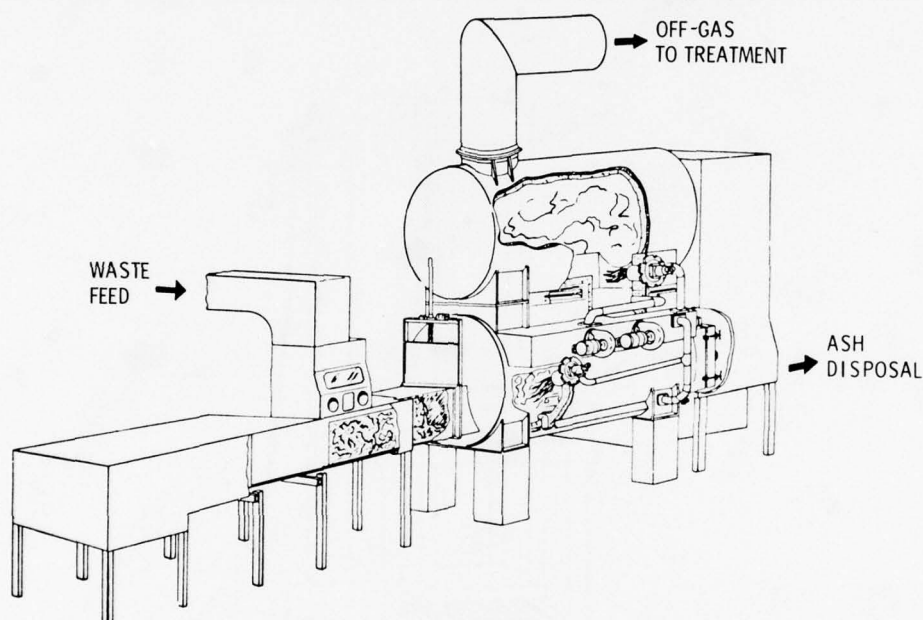


FIGURE 4.4.9. Controlled-Air Incinerator

The incinerator chamber shells and other primary structural components are of carbon steel. The two combustion chambers and the exhaust duct immediately downstream of the upper chamber are lined with 13 cm (5 in.) of high-density plastic refractory, 5.1 cm (2 in.) of mineral wool block, and 0.6 cm (1/4 in.) of mastic stack coating. The 1650°C (3000°F) tolerance plastic refractory is used because it is more easily repaired and more resistant to thermal shock than the more common castable type. The mastic provides diffusion protection for the carbon steel shells, preventing corrosive attack by combustion product acid vapors such as hydrogen chloride and SO_3 .

Incinerator modifications to ensure containment of radioactive materials and to facilitate maintenance of mechanical process equipment include 1) relocation of the combustion-gas supply equipment and controls to a glove box enclosure outside of the incinerator cell, 2) full enclosure of the ram feeding mechanism, and 3) secondary seals for all flanges.⁽¹¹⁾

Off-gas Treatment Subsystem. The overall gas-treatment system equipment layout is shown in Figure 4.4.10. The system comprises, in order of direction of gas flow, a quench column for gas cooling, a venturi scrubber for particle removal, a packed column for acidic gas removal, a condenser for further gas cooling and consequent water removal, a reheater to prevent condensation in the filter system, and roughing and HEPA filters for final particle removal.

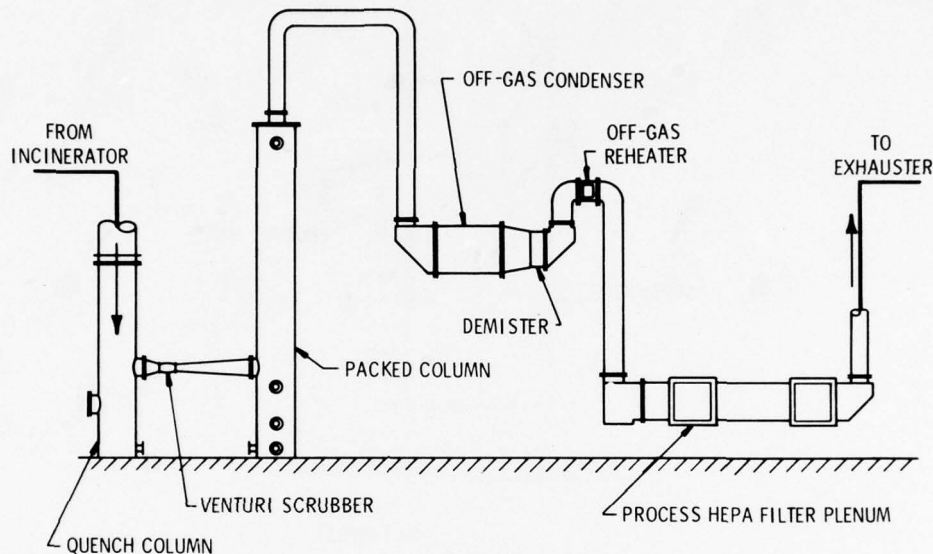


FIGURE 4.4.10. Off-gas Treatment Subsystem

Quench Column. The quench column, which cools the gas from 1400°C (2500°F) to 77°C, is shown in Figure 4.4.11. The quench column contacting section consists of a refractory-lined plastic pipe 25 cm (10 in.) in diameter (inside) and reinforced with fiber glass, with a weir, three spray lances, and an exit nozzle. The weir keeps the refractory wall fully wetted. Spray lances, located below the weir, atomize scrub solution for better gas-liquid contact. The weir, spray lances, and nozzles are fabricated from Hastelloy C-276 for corrosion resistance. A separator for liquid deentrainment is located below the contacting section.

Venturi Scrubber. The variable-throat venturi scrubber, located between the quench column and packed column, has a converging cone 33 cm (13-in.) long and a diverging cone 130 cm (50 in.) long. The throat is a Teflon-lined clamp valve 13 cm (5 in.) in diameter, which allows the pressure drop to vary between 0.025 and 0.20 atmospheres (10- and 80-in. H₂O).

Packed Column Scrubber. The packed column scrubber, illustrated in Figure 4.4.12, reduces the gas-phase hydrogen chloride concentration by counter-current contact with condensate and/or fresh water. Polypropylene supports in the scrubber hold a bed of polypropylene packing 280 cm (110 in.) deep. Condensate and fresh water are introduced at the top of the column through a polypropylene distributor.

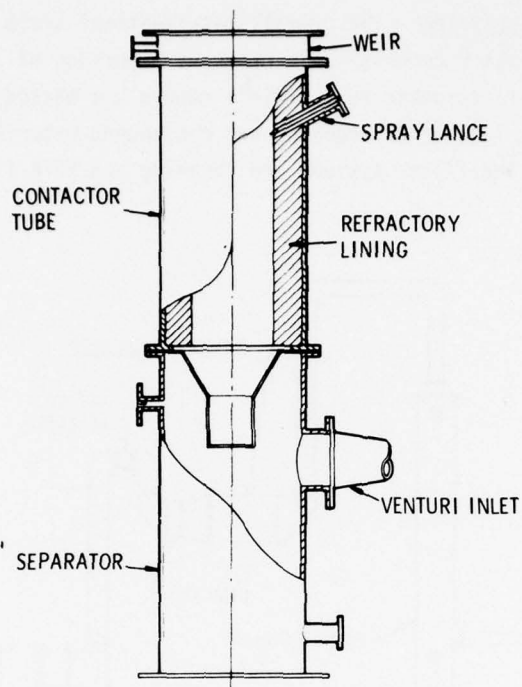


FIGURE 4.4.11. Quench Column

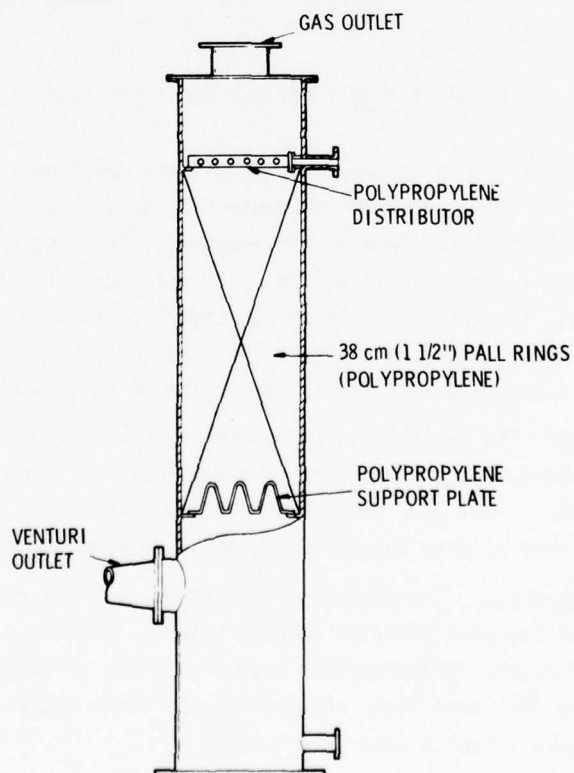


FIGURE 4.4.12. Packed Column Scrubber

Condenser and Mist Eliminator. The condenser and mist eliminator are commercial models placed within special enclosures designed to allow maintenance access and to withstand the 0.2 atmosphere (3 psi) vacuum used in this process. The condenser core contains two coils, consisting of several rows of finned tubes, which are coated with a baked phenolic to prevent chloride corrosion. The mist eliminator located downstream from the condenser has a fiber glass frame and plastic elements.

Reheater. A reheater is provided to vaporize any entrained liquid that passes through the demister and insure that no liquid reaches the filters. The 18-element reheater unit, with an 18 kW capacity, is housed above the centerlines of the condenser/mist eliminator module and the HEPA filter module to prevent radiant heating of the adjacent modules. This unit is also placed within a specially designed housing allowing maintenance access and operation at 0.2 atmosphere (3 psi) vacuum.

Filters. HEPA filter frames are commercial models located in housing specially designed to operate at 0.2 atmosphere (3 psi) vacuum. The filter module houses two frames in series. The first frame uses three 61 x 61 x 15-cm (2 x 2 x 1/2-ft) prefilters and three 61 x 61 x 30-cm (2 x 2 x 1-ft) HEPA filters. The second frame is similar but does not have prefilter provisions. Both frames are rated for 100 m³/min (3600 CFM) at 0.0025 atmosphere (1 in. H₂O) and are supplied with bag-out doors. The support enclosure is fitted with hatches providing access to the bag-out doors, and with in-place dioctylphthalate (DOP) filter testing ports. The HEPA filter module is fabricated of carbon steel since there is little possibility of condensate reaching it.

Blower. The induced-draft blower produces 0.79 atmospheres (11.6 psia) static pressure at 85 m³/min (3000 ft³/min) with a discharge pressure of one atmosphere (14.7 psia). An identical back-up blower is required.

Scrubbing Solution Recycle Equipment. Filters, coolers, and tankage used in this portion of the process are standard items and are briefly described in Section 4.4.1.3.

Scrubbing Solution Concentration System. The concentration system, which handles the total output of both the ILW and LLW incinerators at the FRP, is adjacent to the ILW incineration system. Scrub solution from the LLW system is transferred to the ILW area for concentration. The concentration system consists of a collection tank, a concentrator, and a concentrate collection tank. The stainless steel collection tank provides in excess of a one day surge capacity of 9.5 m³ (2500 gal). The stainless steel concentrate collection tank has a capacity of 1.9 m³ (500 gal). The concentrator, shown in Figure 4.4.13, is a vertical-tube, forced-circulation design and is constructed of prestressed stainless steel, with titanium circulation pump internals and boiler tubes. The concentration system is designed for an average feed rate of 20 l/min (5 gal/min) and provides an 85% volume reduction.

Shielding and Remote Handling Equipment. Because of the penetrating radiation from ILW generated at the FRP, shielding is required throughout the incineration process. The process is contained in cells with concrete walls 60 to 90 cm (2 to 3 ft) thick, as shown in Figure 4.4.7. Shielded viewing windows are provided as needed for the various operations to be

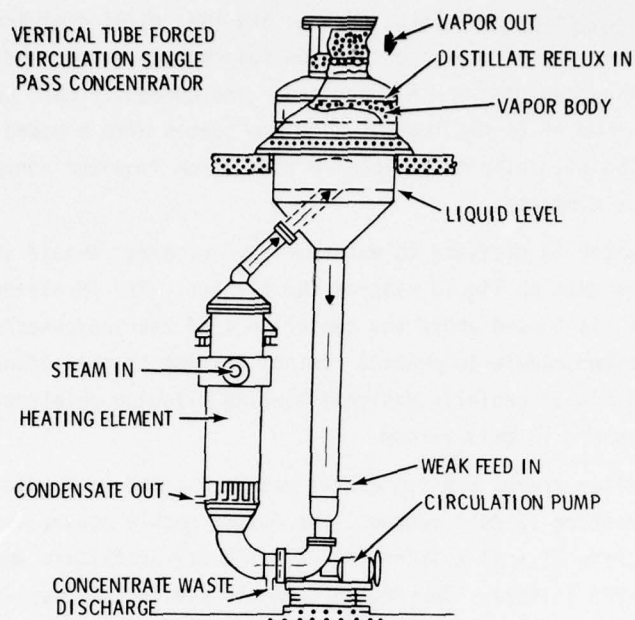


FIGURE 4.4.13. Scrubbing Solution Blowdown Concentrator

carried out by manipulators. Waste being transported to the incineration facility from the main plant often requires the use of shielded equipment, such as shielded transport containers, and shielded fork-lift trucks.

4.4.1.5 Operating and Maintenance Requirements for the ILW Incineration Facility at the FRP

The incinerator operation is a semicontinuous process. A number of operating schemes are available in order to optimize manpower scheduling and to interface with manpower requirements for the rest of the FRP complex.

Facility Operation. For maximum refractory life, the incinerator should be operated for approximately 60 to 100 hours continuously before cool-down to remove ash. The length of time that the incinerator can be operated is expected to be about 100 hours but it depends on the ash content of the waste. About 24 hours should be adequate for incinerator cool-down, ash removal and incinerator reheating; an entire incineration cycle can be performed in about five days. During the approximately 100 hours of incineration operation, the work is on a 24-hr/day basis. Since only 3000 hours (5100 hours if non-TRU waste is also incinerated in this incinerator) of operation per year are required to process the waste, considerable time is available for maintenance and for feed preparation to be carried out within the limits of cell storage space during nonoperating periods.

Operations include transfers into and out of cells; waste feed preparation and transfer within the cell by use of manipulators; assay and x-ray equipment operation and monitoring from outside the cells; operation of incinerator and off-gas system controls and instrumentation from outside the cells; ash removal and packaging using manipulators; and normal maintenance and replacement activities.

Maintenance. Equipment items in the cells are modified as needed to provide for ease of remote maintenance or disposal. Some items require removal from the cell for maintenance, whereas maintenance on others, such as the low-speed shredder, can be performed within the cell, including change of the bearings and cutters. The shredder can also be removed from the cell, if required, for decontamination and maintenance elsewhere. To the extent possible, all operating controls for the process will be located outside of the cells to minimize maintenance efforts.

Although the overall facility is designed to last for the life of the FRP (30 years), the refractory must be changed about every ten years. At that time, the entire primary and secondary chambers are replaced.

The off-gas treatment cell remains relatively clean compared to the incinerator cell because the particles are primarily contained in the scrubbing solution. Further, the concentration of radioisotopes is much lower in the off-gas components. Therefore, personnel entry for minor maintenance and filter changes should not require decontamination efforts. The concrete cell walls lower the exposure to personnel normally stationed in the operating area.

Staffing. Estimated staffing requirements for the ILW incineration facility are shown in Table 4.4.9. Daily manpower requirements vary with twelve operators (four per shift) being required during processing periods and fewer being required during waste shipping and receiving. Monitoring personnel requirements are highest during cell load-in and load-out and maintenance operations.

TABLE 4.4.9. Staffing Requirements for the Fuel Reprocessing Plant ILW Incineration

Job Description	Personnel Required, man-yr/yr
Operators	10
Radiation monitors	3
Maintenance craftsmen	0.5

Supplies and Utilities. Table 4.4.10 shows the supplies used in the reference ILW incineration facility. Table 4.4.11 lists utilities required for facility operation.

TABLE 4.4.10. Supply Requirement for the Fuel Reprocessing Plant ILW Incineration Facility

Supply	Use	Annual Requirements
NaOH	pH control in off-gas scrubbing solution	2×10^4 kg
Cardboard boxes	Repackaging of sorted and shredded waste to be incinerated	5100
Steel drums (55-gal)	Packaging of pelletized filter media	400

TABLE 4.4.11. Utility Requirements for the Fuel Reprocessing Plant ILW Incineration Facility

Utility	Use Rate	Annual Requirement ^(a)
Electricity	800 kW	2.4×10^6 kWh
Propane	15 m ³ /hr	4.5×10^4 m ³ (STP)
Steam	360 kg/hr	1.1×10^6 kg
Water consumed	2.1 m ³ /hr	6300 m ³

a. Based on 3000 hours operation/year.

4.4.1.6 Secondary Radioactive Wastes from the ILW Incineration Facility at the FRP

Secondary radioactive wastes produced by the ILW incineration facility are shown in Table 4.4.12.

The amount and composition of ash resulting from incineration of a given waste component varies greatly depending on factors such as incinerator efficiency (amount of unburned carbon) and the amounts and types of filler materials and coloring agents. For example, the ash content of polyvinyl chloride (PVC) can vary between 0.6 and 6.1 wt% with essentially no unburned carbon. Because the ash content of the feed cannot be predicted, the following assumptions are used here:

- The composite ash produced is 8 wt% of the solids fed to the incinerator.
- The ash contains essentially all the radioactivity in the incinerator feed to the primary incinerator chamber except that it contains no tritium and only 0.1% of the iodine-129. It also contains three-fourths of the activity in the waste (degraded extractant) fed to the secondary incinerator chamber except for the iodine-129. The activity on wooden filter frames is assumed to be 2% of the total on the filters.
- The bulk density of the ash is 240 kg/m³ (15 lbs/ft³).

Scrubbing solution concentrate composition also varies somewhat with variation of feed composition. Table 4.4.13 gives the approximate average composition expected based on incineration of the wastes shown in Table 4.4.1. The activities shown for the scrub solution concentrate in Table 4.4.12 are based on the following estimates or assumptions:

- Both iodine-129 and tritium are essentially completely volatile in both chambers of the incinerator.
- Fifty percent of iodine-129 is removed by the scrub solution; in the concentrator, it evaporates in proportion to the amount of water evaporated.
- Tritium as H₂O in the incinerator off-gas equilibrates completely with other water at all stages.

TABLE 4.4.12. Secondary Radioactive Wastes from the Fuel Reprocessing Plant ILW Incineration Facility

Description	Volume, m ³ /yr	Radioactivity Factor ^(a)	
Incinerator ash (stream 22a, Table 4.4.4)	70	³ H	0
		¹²⁹ I	1×10^{-3}
		Zr, Nb, Ru, Rh	0.48 ^(b)
		Other fission products	0.14 ^(b)
		Pu	0.23 ^(b)
		Other TRU	0.18 ^(b)
		Activation products	1.0 ^(b)
Scrubbing solution concentrate (stream 55, Table 4.4.7)	150	¹²⁹ I	0.07
		³ H	0.14
		Zr, Nb, Ru, Rh	0.011 ^(c)
		Other fission products	0.002 ^(c)
		Pu	0.01 ^(c)
		Other TRU	0.02 ^(c)
		Activation products	0.001 ^(c)
Noncombustible general trash and failed equipment	2	³ H	0
		¹²⁹ I	0
		Other fission products and activation products	1×10^{-3}
		Actinides	1×10^{-4}
Combustible and Compactable Waste	20	³ H, ¹²⁹ I	$1 \times 10^{-6(d)}$
		Zr, Nb, Ru, Rh	$5 \times 10^{-7(d)}$
		Other fission products	$1 \times 10^{-7(d)}$
		Pu	$2 \times 10^{-7(d)}$
		Other TRU	$2 \times 10^{-7(d)}$
		Activation products	$1 \times 10^{-4(d)}$

a. Fraction of the total input activity to the facility (Table 4.4.2) in secondary wastes

b. Obtained using factor of 1.0 on materials fed to primary incinerator chamber (stream 15, Table 4.4.4) and factor of 0.75 on materials fed to secondary incinerator chamber (stream 18, Table 4.4.4)

c. Obtained using factor of 1×10^{-3} on materials fed to primary incinerator chamber (stream 15, Table 4.4.4) and factor of 0.25 on materials fed to secondary incinerator chamber (stream 18, Table 4.4.4)

d. Obtained using factor of 1×10^{-6} on total input to incinerator (streams 15 and 18, Table 4.4.4).

TABLE 4.4.13. Scrub Solution Concentrate from the Fuel Reprocessing Plant ILW Incineration Facility

Volume	1.5×10^5 ℓ /yr
Specific gravity	1.15
Chemical composition	
pH	7 to 9
NaCl	2.7 <u>M</u>
NaHCO ₃	0.7 <u>M</u>
Na ₂ SO ₃ and Na ₂ SO ₄	0.06 <u>M</u>
Na ₂ HPO ₄	0.1 <u>M</u>
Particles	0.2 g/ ℓ

- An off-gas decontamination factor (DF) of 250 occurs in the primary incinerator chamber and a DF of 1 occurs in the secondary incinerator chamber for all nonvolatile fission products, actinides, and activation products.
- 0.1% of the ruthenium is converted to volatile form in the reducing atmosphere of the primary incinerator chamber; 10% is converted to volatile form in the secondary chamber; this volatile ruthenium is reconverted to nonvolatile ruthenium in the off-gas scrubbing subsystem and is efficiently removed in the off-gas filters.
- The filters for the scrub solution recycle remove 75% of the activity reaching them except for iodine-129 and tritium.

The compositions of the scrubbing solution concentrate in Tables 4.4.12 and 4.4.13 reflect only the contents and volume attributable to the ILW incinerator. Since the actual concentrate is a blend of the concentrates attributable to incineration of both ILW and LLW, the actual composition would be changed accordingly. The scrubbing solution concentrate is sent to the facility for immobilization of wet waste and particulate solids (Section 4.7).

The noncombustible general trash and failed equipment shown in Table 4.4.12 include the annual fraction of the incinerator primary and secondary chamber replacement, which is expected to occur about every ten years. This waste is sent to the treatment facility for failed equipment and other noncombustible waste (Section 4.3). Combustible general trash, including scrub solution recycle filters, is immediately recycled to the incineration process.

4.4.1.7 Emissions from the ILW Incineration Facility at the FRP

Estimated facility emissions are shown in Table 4.4.14. The activity levels in the gaseous emissions are based on the following estimates, in addition to those previously noted in Section 4.4.1.6:

- a particle DF (input gas/output gas) of 50 in the venturi scrubber
- a DF of 10 for the prefilter and 10^3 each for two stages of HEPA filters

TABLE 4.4.14. Emissions from the Fuel Reprocessing Plant
ILW Incineration Facility

Emission	Description	Annual Quantity	Radioactivity Release Factor To Atmosphere ^(a)			
Gaseous	Cleaned incinerator off-gas	Air 4 x 10 ⁶ m ³	³ H	0.2		
			¹²⁹ I	0.52		
		HCl 70 kg	Zr, Nb, Ru, Rh	9 x 10 ⁻¹⁵ (b)		
		SO _x 120 kg	Other fission products	2 x 10 ⁻¹⁵ (b)		
		NO _x 270 kg				
		CO 130 kg	Pu	8 x 10 ⁻¹⁵ (b)		
			U	9 x 10 ⁻¹⁵ (b)		
			Other actinides	2 x 10 ⁻¹⁴ (b)		
			Activation Products	8 x 10 ⁻¹⁶ (b)		
		Water evaporated from spent scrubber solutions	H ₂ O 8.5 x 10 ⁴ kg	³ H	0.6	
	¹²⁹ I			0.43		
	Zr, Nb, Ru, Rh			1 x 10 ⁻¹¹ (c)		
	Other fission products			2 x 10 ⁻¹² (c)		
	Pu			1 x 10 ⁻¹¹ (c)		
	U			1 x 10 ⁻¹¹ (c)		
	Other actinides			2 x 10 ⁻¹¹ (c)		
	Activation Products			1 x 10 ⁻¹² (c)		
	Minor accidents integrated annual release				³ H	2 x 10 ⁻⁵
					¹²⁹ I	2 x 10 ⁻⁵
			Zr, Nb, Ru, Rh	7 x 10 ⁻¹³		
			Other fission products	2 x 10 ⁻¹³		
			Pu	3 x 10 ⁻¹³		
			Other actinides	2 x 10 ⁻¹³		
		Activation Products	2 x 10 ⁻¹²			
Cooling Tower Water	Evaporated (T = 38°C)	5.4 x 10 ⁶ kg				
	Drift (T = 38°C)	2.6 x 10 ⁴ kg				
	Blowdown (T = 27°C)	9.4 x 10 ⁵ kg				
Other	Heat					
	to cooling tower	3.6 x 10 ³ MW-hr (1.2 x 10 ¹⁰ BTU)				
	in gaseous emission	1.3 x 10 ³ MW-hr (4.5 x 10 ⁹ BTU)				

- a. Fraction of total input activity to the facility (Table 4.4.2) released to the atmosphere. Includes DF from main plant APS where applicable. Released over 3000 hr/yr.
- b. Obtained using factor of 8×10^{-16} on materials fed to primary incinerator chamber (stream 15, Table 4.4.4) and factor of 2×10^{-13} on materials fed to secondary incinerator chamber (stream 18, Table 4.4.4).
- c. Obtained using factor of 1×10^{-12} on materials fed to primary incinerator chamber (stream 15, Table 4.4.4) and factor of 2.5×10^{-10} materials fed to secondary incinerator chamber (stream 18, Table 4.4.4).

- A DF of 10^5 for the water vapor from the scrubbing solution concentrator.

The DFs are conservative for the following reasons:

- The incinerator DF (250) is based on an off-gas particle loading of 2.2 g/m^3 , with a feed rate of 68 kg/hr. Particle loadings of only 1.25 and 1.45 g/m^3 at 12% CO_2 were demonstrated in EPA certification tests in a similar unit burning 225 kg/hr of Public Health Service standard waste.⁽³⁾
- The venturi DF, under normal operating conditions, is close to 100.⁽³⁾

No credit is taken for particle removal by the quench column, the packed column scrubber, the condenser, or the mist eliminator. The values for the cleaned incinerator off-gas in Table 4.4.14 are based on an average gas flow of $21 \text{ m}^3/\text{min}$ and 3000 hours of operation per year.

While there is considerable uncertainty in estimating all of these radionuclide releases, the release of ruthenium in the cleaned off-gas is especially questionable because of the uncertainties in fractional conversion to volatile forms and re-conversion of volatile to particulate forms. The listed estimated release, which assumes complete re-conversion of volatile ruthenium to particulate forms followed by removal as a typical particulate in the off-gas system, may be understated. However, even if this release is understated by as much as a factor of 10^{10} , the ruthenium release from the ILW incineration facility would then still be about a factor of ten lower than the ruthenium release estimated in the FRP treated dissolver and vessel off-gas streams (Sections 4.9 and 4.10), and would not be the controlling release from the plant as a whole.

An estimate of the integrated annual release due to minor accidents (Section 4.4.1.9) for this facility is included in Table 4.4.14. It was developed by weighing the minor accident releases by their expected frequencies and summing the quantities for all identified minor accidents. In addition, a contingency was included in the integrated release to account for unidentified minor accidents and to compensate for the uncertainty in expected frequency information.

4.4.1.8 Decommissioning Considerations for the ILW Incineration Facility at the FRP

The expected useful lives for the primary and secondary incinerator chambers are each ten years. It is anticipated that the activity levels in the refractory of these chambers will not build up to more than one percent of the total activity of all the feed processed through the incinerator in one year. The other major equipment associated with the ILW incineration facility is expected to have a useful life equal to that of the overall plant. No appreciable radioactivity buildup in the equipment beyond a rapidly attained steady state value is expected except that noted in the incinerator refractory.

4.4.1.9 Postulated Accidents for the ILW Incineration Facility at the FRP

Postulated minor and moderate accident scenarios for the ILW incineration facility are given in Tables 4.4.15 and 4.4.16. In developing the release estimates given in the tables, it is estimated that in any fire in the feed preparation line, 50% of the activity in trash burned would be released to the cell filters. In the minor fire, no more than 1% of the trash (16 kg) at maximum loading in the feed preparation system would be expected to burn, and

TABLE 4.4.15. Minor Accidents for the Fuel Reprocessing Plant
ILW Incineration Facility

Accident No. and Description	Sequence of Events	Safety System	Release
4.4.1 - Loss of cooling water to incinerator off-gas treatment system; expected frequency, ~ 0.05 per year.	<ol style="list-style-type: none"> 1. Cooling water flow to off-gas treatment system fails. 2. Humidity in off-gas rises. 3. HEPA filters slowly plug because of condensing moisture. 4. HEPA filter blockage shuts down system in about 30 minutes. 	<ol style="list-style-type: none"> 1. Slow (~ 30 min) blockage of air-flow allows adequate time for equipment shutdown to be carried out. 2. A two-hour back-up supply of pressurized water to quench column prevents other effects of coolant loss from occurring. 	None.
4.4.2 - Minor fire in feed preparation system; expected frequency, 0.2 per year.	<ol style="list-style-type: none"> 1. Fire starts in trash in feed preparation area. 2. Small fire is detected and extinguished. 	<ol style="list-style-type: none"> 1. Well-designed automatic fire suppression system. 2. Additional manually operated fire suppression equipment. 	4×10^{-5} of radionuclides in waste sent annually to temporary storage (stream 14 of Table 4.4.3) released to cell filters.

TABLE 4.4.16. Moderate Accidents for the Fuel Reprocessing Plant
ILW Incineration Facility

Accident No. and Description	Sequence of Events	Safety System	Release
4.4.3 - Major fire in feed preparation line; expected frequency 0.01/yr.	<ol style="list-style-type: none"> 1. Feed preparation line contains maximum loading of waste (24 hrs of incinerator feed). 2. Fire initiates in waste. 3. Fire suppression system does not operate. 4. Cell atmospheric filters fail because of flames. 	<ol style="list-style-type: none"> 1. Well-designed automatic fire suppression system would be used. 2. Additional manual or redundant automatic fire suppression equipment could be used. 3. Proper location of cell filters in relation to location of major fuel load minimizes chance of flame intrusion. 	4×10^{-3} of radionuclides in waste sent annually to temporary storage (stream 14 of Table 4.4.3) released directly to the FRP APS.
4.4.4 - Explosion in feed preparation system; expected frequency 0.02/yr.	<ol style="list-style-type: none"> 1. Small amounts of explosive material in waste. 2. Such material explodes during sorting operation. 	<ol style="list-style-type: none"> 1. Explosives or explosive chemicals are not used in FRP operation. 2. Waste form designed to prevent formation of explosive material. 	1×10^{-4} of radionuclides in waste sent annually through feed preparation system (streams 1 and 2 of Table 4.4.3) released to cell filters.
4.4.5 - Incinerator explosion; expected frequency 0.01/yr.	<ol style="list-style-type: none"> 1. Flame-out occurs in incinerator. 2. Explosive reignition of propane-air mixture in incinerator causes breach of incinerator. 3. 50% of ash in incinerator at maximum load is suspended in cell air. 	<ol style="list-style-type: none"> 1. Incinerator control system greatly reduces probability of occurrence. 2. Automatic fire-control sprinklers would activate, reducing airborne particles. 	1.7×10^{-2} of annual incinerator primary chamber feed activity (stream 15 of Table 4.4.3) except ^3H and ^{129}I released to cell filters in 0.5 hr.

the fire suppression system would extinguish the fire before damage to the cell ventilation filters occurred. The major fire could only occur through the rare event of complete failure of the fire suppression system at the time of the fire. Such a fire, burning the entire 1600 kg of inventory might breach the cell filters through flame intrusion. The release in the major fire is estimated as 50% of the entire 1600 kg of inventory. The low frequency of a major fire reflects the very high reliability of well-designed and operated automatic fire suppression equipment. For a fire to reach a large size, it would have to occur at a time when the automatic fire suppression equipment is inoperative and when neither the operators nor detection equipment would detect it--a very unlikely condition.

For purposes of environmental consequence, several releases for this technology have been designated as umbrella source terms (See Section 3.7, Basis for Accident Analysis). Releases from Accidents 4.4.3 and 4.4.5 involved the largest amounts of activity in their release group from accidents in this waste management system and therefore were selected as umbrella source terms. Source term categories are cross-indexed by accident number in Appendix A of Section 3.

In the analysis of the incinerator explosion (Accident 4.4.5), the maximum propane/air explosion in the incinerator would not be expected to breach the cell filters because of the large cell size in relation to the incinerator. The releases from this accident were calculated as if the incinerator contained the maximum amount of ash (ash is removed batch-wise every 100 hrs) and 50% of the ash reaches the cell filters.

No accidents that could be classified as severe accidents could be realistically postulated for this technology.

4.4.1.10 Costs for the ILW Incineration Facility at the FRP

Estimates have been made, in mid-1976 dollars, of capital, operating and levelized unit cost. A complete description of the cost estimate bases, assumptions and definitions is given in Section 3.8.

Capital Costs. The capital cost estimate, shown in Table 4.4.17, covers all capital costs specifically resulting from inclusion of the ILW incineration facility as an integral part of the FRP (described in Section 3.2). These costs also include the effect of incremental additions to utilities such as electricity, compressed air and heat, ventilation and air conditioning (HVAC) as well as the cable, piping and other bulk materials incorporated directly into the intermediate-level waste incineration facility. However, general FRP costs for such services as laboratories and warehousing are not allocated to the reference facility.

The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation with the exception of working capital and the cost of shielded waste containers required to hold untreated waste packages (considered part of the FRP operation cost).

Operating Costs. Table 4.4.18 tabulates the operating cost components for ILW incineration. Direct labor costs are based on the manpower estimates in Table 4.4.9. Process material and utility costs are based on the requirements for both TRU and Non-TRU wastes. Annual maintenance materials are estimated at 3% of initial major equipment cost. Overhead and miscellaneous costs are calculated as described in Section 3.8.

Levelized Unit Costs. The total levelized unit cost, including the levelized capital and operating components, is shown in Table 4.4.19. The cost calculation assumes private ownership and a 15-year economic life for the facility.

TABLE 4.4.17. Capital Cost Estimates for the Fuel Reprocessing Plant ILW Incineration Facility

Cost Element	Manhours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		18	1900	200	2100
Building and structures		80	900	980	1880
Bulk materials		22	300	270	570
Site improvements					
Subtotal of direct site construction costs		120	3100	1450	4550
Indirect site construction costs	30	25	550	700	1250
Total field cost	30	145	3650	2150	5800
Architect-engineer services					1000
Subtotal					6800
Owner's cost					2000
Total facility cost					8800
Estimate accuracy range					±25%

TABLE 4.4.18. Operating Cost Estimate for the Fuel Reprocessing Plant ILW Incineration Facility

Cost Element	Annual Costs, \$1000s
Direct labor	215
Process materials	25
Utilities	130
Maintenance materials	65
Overhead	275
Miscellaneous	40
TOTAL	750 +50% -25%

TABLE 4.4.19. Levelized Unit Cost Estimate for the Fuel Reprocessing Plant ILW Incineration Facility

Cost Element	Unit Cost, \$/kg HM
Levelized Capital Charge	1.60
Levelized Operating Charge	.30
Levelized Total Unit Cost	1.90 ±35%

4.4.1.11 Construction Requirements for the ILW Incineration Facility at the FRP

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating this impact.

Project Schedules and Construction Manpower. The schedule for engineering, procurement and construction of the ILW incineration facility is an integral factor in the overall schedule for the construction phase of the FRP. The field labor force estimated for the construction of the ILW incineration facility is tabulated below:

	Man-hours, 1000s
Manual field labor	145
Nonmanual field labor	30
Total field labor	175

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials and services provided at the site of the FRP while offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is shown below:

	Costs, \$1000s
Onsite	2400
Offsite	6400
Total	8800

Site Requirements. No additional site requirements beyond those for the FRP are identified for the ILW incineration facility. Land commitments for the facility are included with those of the FRP.

Water. Approximately 2300 m^3 (0.6×10^6 gal) of water are required during construction.

Construction Materials. Materials committed to facility construction are:

Concrete	1500 m^3	(2000 yd^3)
Steel	300 MT	(350 tons)
Copper	0.9 MT	(1 ton)
Lumber	60 m^3	(25 MFBM)

Energy. Energy resources used during construction are:

Propane	19 m^3	(5,000 gal)
Diesel fuel	190 m^3	(50,000 gal)
Gasoline	130 m^3	(35,000 gal)
Electricity		
Peak demand	160 kW	
Total consumption	100,000 kWh	

Transportation Requirements. No separate transportation requirements for the ILW incineration facility have been identified beyond those for the FRP.

4.4.1.12 Effects of Fuel Cycle Options on ILW Incineration at the FRP

The reference process for incineration of ILW at the FRP assumes reprocessing of LWR fuel and recycling the recovered uranium and plutonium. The following alternative fuel cycle modes have also been assessed insofar as they relate to incineration of ILW.

No Recycle. The no recycle option eliminates the FRP; no ILW is generated and incineration is not required.

Uranium Recycle Only With Plutonium to a Repository. For uranium recycle only, with plutonium sent to a repository, the ILW incineration facility design and operation would be virtually the same as in the case of uranium and plutonium recycle.

Uranium Recycle Only With Plutonium to the HLW. In the case of uranium recycle only, with plutonium to the HLW, the main FRP would operate much the same as in the reference case, but without a PuO_2 conversion facility. This would result in some difference in the volume, nature, and activity of the ILW waste (Table 4.4.1). The volume of general trash would be reduced by only about 4%, but the plutonium content in the incinerator feed would be reduced by a factor of five. The volume of ventilation filters processed would be reduced by about 12%; however, the plutonium content on the filter media would be reduced by a factor of 200, and no metal filter frames would be processed. These minor changes would have little, if any, effect on facility design and operation.

4.4.2 Incineration of Low-Level Waste (LLW) at the Fuel Reprocessing Plant

The low-level waste (LLW) portion of the combustible and compactable waste, has surface gamma readings of <200 mR/hr in 55-gal steel drums. The general trash from the main FRP, excluding the PuO_2 conversion facility, falling in this activity category is fed to the LLW incineration process.

The LLW incineration process and equipment are virtually identical to those of the intermediate-level waste (ILW) incineration facility except for lower shielding requirements and differences in feed stream components (the LLW facility does not process ventilation filters or degraded extractant).

Incineration of low-gamma-activity radioactive waste has been practiced for over 25 years by nations involved with nuclear technology. A list of units and discussions of installation experiences are available from several sources. (2,5-7)

4.4.2.1 Alternatives for LLW Incineration at the FRP

The selected reference treatment system for LLW at the FRP is based on controlled-air incineration, (2-4) with a high-energy aqueous off-gas treatment system. Alternatives to controlled-air incineration for the ILW are discussed in Section 4.4.1.1 and apply equally to the selected LLW reference process.

4.4.2.2 Design Basis for the LLW Incineration Facility at the FRP

The following assumptions were made in design of the LLW incineration facility:

- The facility is associated with the operation of the reference 2000-MTHM fuel reprocessing plant (FRP). All supporting facilities and services are provided by the reprocessing plant.
- The scrub solution from the LLW incineration facility is transferred to the ILW facility for concentration in the ILW scrub solution concentrator.
- Remote operation is not required.
- The facility receives 2400 m³ of combustible trash per year which is that portion of the combustible general trash from the main FRP having a surface dose rate reading of <200 mR/hr in 55-gal steel drums. The source, composition, properties, and amount of this waste are shown in Table 4.4.20. The annual quantities of the major radionuclides in the waste are shown in Table 4.4.21.

TABLE 4.4.20. Combustible and Compactable Transuranic Waste Processed in the Fuel Reprocessing Plant LLW Incineration Facility

<u>Source</u>	<u>Composition, wt%</u>	<u>Density, kg/m³</u>	<u>Volume, m³/yr</u>
Main plant combustible trash	Paper/rags	40	2400
	PVC	20	
	Neoprene	11	
	Polyethylene	14	
	Latex	11	
	Wood	4	

- The incineration facility is designed to process the LLW in 4300 hours of incinerator operation per year.
- The LLW incineration facility includes, in addition to the incinerator itself, a feed preparation subsystem that includes sorting and shredding capability, a feed assay subsystem, and an off-gas treatment subsystem that includes aqueous scrubbing.
- The incinerator and off-gas treatment train are designed to handle feed material consisting of up to 100% of any one of the major combustible general trash components (cellulosics, plastic, rubber, etc.).
- Incinerator ash and off-gas scrubbing solution concentrates are sent to the facility for immobilization of the wet waste and particulate solids (Section 4.7) for final treatment.
- The assay subsystem provides inventory control for fissile materials in the incineration process and prevents cross-contamination by other classes of waste.
- All utilities required for an orderly process shutdown, such as cooling water, power, ventilation, and compressed gas for pneumatic process controls, are assured by back-up systems.

TABLE 4.4.21. Radionuclide Content of Waste Treated in the Fuel Reprocessing Plant LLW Incineration Facility(a,b)

Radionuclides	Ci/yr
<u>Fission Products</u>	
$^{90}\text{Sr} + ^{90}\text{Y}$	2.4×10^{-1}
$^{95}\text{Zr} + ^{95}\text{Nb}$	2.2×10^{-2}
$^{106}\text{Ru} + ^{106}\text{Rh}$	7.6×10^{-1}
$^{134}\text{Cs} + ^{137}\text{Cs} + ^{137\text{m}}\text{Ba}$	6.0×10^{-1}
$^{144}\text{Ce} + ^{144}\text{Pr}$	9.6×10^{-1}
All other	2.0×10^{-1}
TOTAL	2.8
<u>Actinides</u>	
^{239}Pu	7.2×10^{-4}
^{241}Pu	3.5×10^{-1}
Other Pu	1.2×10^{-2}
$^{242}\text{Cm} + ^{244}\text{Cm}$	3.4×10^{-2}
All other	1.8×10^{-3}
TOTAL	0.4

- a. Based on waste characterization Table 3.3.34, assuming uranium and plutonium recycle, 2000 MTHM/yr reprocessed 1.5 years out of reactor.
 b. Volume - 2400 m³/yr.

- The LLW incinerator facility is designed to withstand design-basis natural phenomena, including earthquakes and tornadoes, and to prevent penetration by maximum credible fire and/or explosion.

4.4.2.3 The LLW Incineration Process at the FRP

The controlled-air incinerator and off-gas cleaning equipment (based on proven technology modified to meet radiological health and safety standards) are identical to the ILW incineration system discussed in Section 4.4.1. The process, with the exception of the activity levels and nature of feed streams processed, is the same as the ILW incineration process discussed in Section 4.4.1.3. Like the ILW incinerator, the performance data for the LLW incineration facility represent current best estimates but are not based on demonstrated tests with radioactive wastes.

The process flowsheet for the LLW incineration facility is shown in Figure 4.4.14. The treatment process can best be described in terms of its subsystems: feed preparation, assay, incinerator charging, incineration, ash collection, off-gas treatment, scrubbing solution recycle, scrubbing solution concentration, and auxiliary utilities.

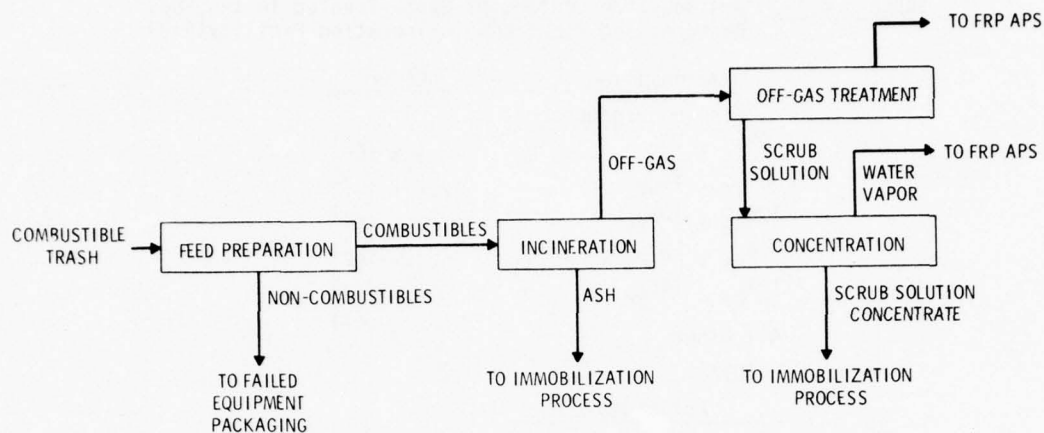


FIGURE 4.4.14. Process Flowsheet for the LLW Incineration Facility at the Fuel Reprocessing Plant

Although scrubbing solution concentration is part of the LLW process, the concentrator is part of the ILW facility, and both scrub streams are concentrated in the ILW concentrator. The portion of the volume, compositions, and activity of this stream attributable to LLW off-gas scrubbing blowdown are treated in the flowsheets in this section rather than in Section 4.4.1.3 in order to better define the effluents (secondary wastes and releases) and costs resulting from processing the LLW waste.

Feed Preparation. The function and operation of the feed preparation subsystem is to make the waste feed materials compatible with the incinerator and is the same as that described in Section 4.4.1.3 except for the absence of ventilation filters in the feed and the equipment for processing them. The LLW facility, because of its lower activity feed, is not remotely-operated in shielded cells. The flow diagram and stream data for the feed preparation subsystem are given in Figure 4.4.15 and Table 4.4.22, respectively.

Assay. The assay subsystem for the LLW incineration facility has the same function as the subsystem described in Section 4.4.1.3. An assay system for LLW would probably require less development than would the assay system for ILW.

Incinerator Charging. The function and operation of the LLW ram feeder are the same as that discussed in Section 4.4.1.3 for the ILW incinerator. A different method of loading the ram feeder would be used in the glovebox operation of the LLW incinerator compared to the shielded ILW incinerator operation. With the LLW incinerator, a device called the side ram elevates the waste packages from the waste storage glovebox and displaces them into the primary ram feeder loading chamber. Waste packages are removed manually from storage, placed in a pneumatic elevator, lifted approximately 61 cm into the side ram feed chamber, and displaced by the side ram through an air lock into the primary ram loading chamber.

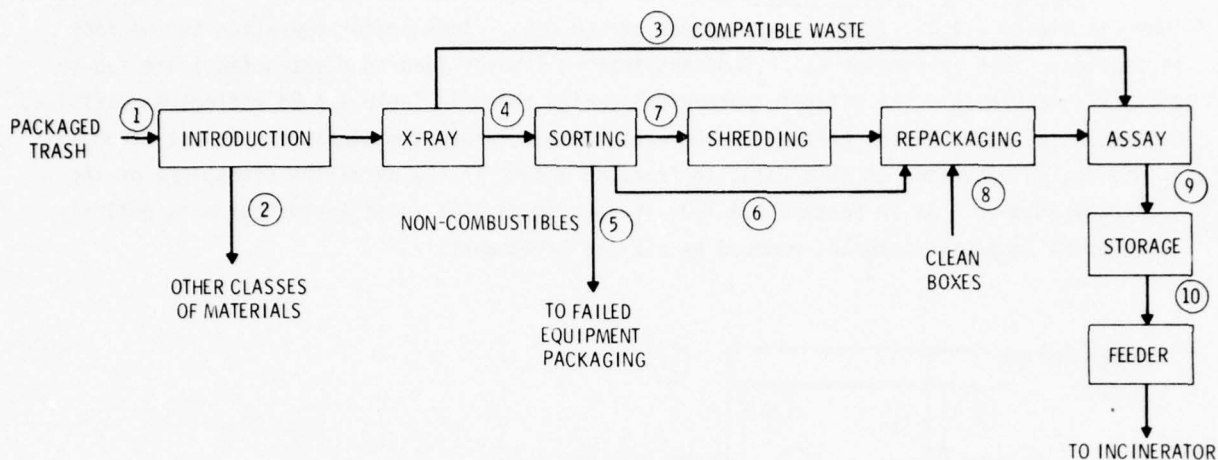


FIGURE 4.4.15. Feed Preparation Subsystem Flow Diagram for the Fuel Reprocessing Plant LLW Incineration Facility (Circled numbers refer to stream numbers given in Table 4.4.22)

TABLE 4.4.22. Fuel Reprocessing Plant LLW Incinerator Feed Preparation Stream Flow Data

Stream Number	Description	Rate ^(b)	Radioactivity Factors ^(a)	
			Fission Products	Actinides
1	Packaged waste, general trash	290,000 kg/yr	1.0	1.0
2	Other classes of materials (included for completeness)	0	0	0
3	Compatible wastes (75% of general trash)	218,000 kg/yr	0.75	0.75
4	Wastes requiring sorting (25% of general trash)	72,000 kg/yr	0.25	0.25
5	Noncombustibles for packaging with failed equipment (included for completeness)	0	0	0
6	Sorted combustible waste not requiring feed shredding	35,000 kg/yr	0.12	0.12
7	Combustible waste requiring feed shredding	37,000 kg/yr	0.13	0.13
8	New boxes for repackaging waste	5,300 boxes/yr	0	0
9	Waste to storage	290,000 kg/yr	1.0	1.0
10	Waste to incinerator	68 kg/hr (290,000 kg/yr)	1.0	1.0

a. Fraction of input activity (Table 4.4.21)

b. Rates in units of hours are instantaneous rates based on 4300 hr/yr of incinerator operation.

4.4.44

Incineration and Ash Collection. The incineration and ash collection flow diagram is shown in Figure 4.4.16; Table 4.4.23, gives stream data. Incinerator operation is the same as that described in Section 4.4.1.3 except that no liquids (degraded extractant) are fed to the LLW incinerator. The volatile ruthenium species shown in Table 4.4.23 reflect an estimated 0.1% volatilization in the primary incinerator chamber, where the atmosphere is not strongly oxidizing; no reduction of this volatile fraction occurs in the oxidizing atmosphere of the secondary chamber. As in Section 4.4.1.3, it is assumed that volatile ruthenium is entirely reconverted to particulate and removed by off-gas treatments.

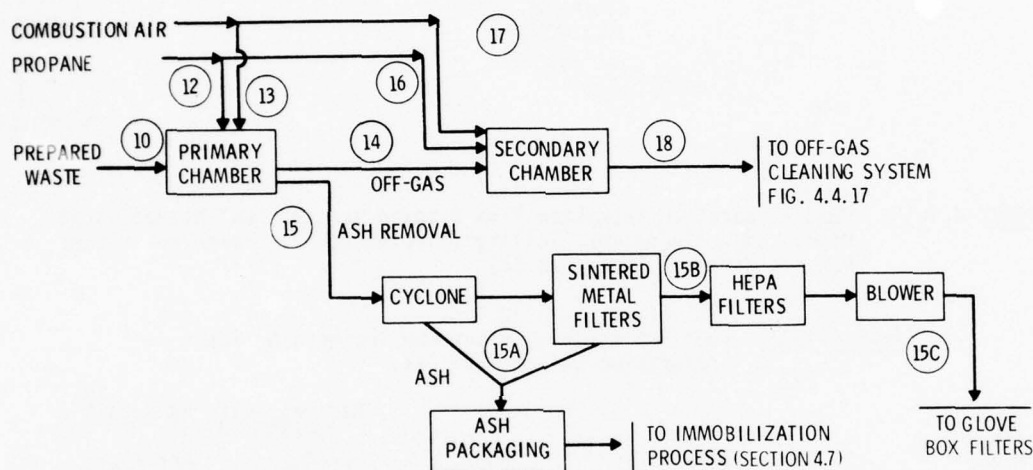


FIGURE 4.4.16. Incineration and Ash Collection Flow Diagram for the Fuel Reprocessing Plant LLW Incineration Facility (Circled numbers given in Table 4.4.23.)

TABLE 4.4.23. Incineration and Ash Collection Stream Flow Data for the Fuel Reprocessing Plant LLW Incineration Facility

Stream Number	Description	Rate ^(b)	Radioactivity Factors ^(a)	
			Fission Products	Actinides
10	Waste to incinerator	290,000 kg/yr	1.0	1.0
12	Primary chamber propane supply	0-50 m ³ /hr (STP)	0	0
13	Primary chamber air supply	4.5-15 m ³ /min (STP)	0	0
14	Primary chamber off-gas	5.7-15 m ³ /min (STP)	4 x 10 ⁻³ 1 x 10 ^{-3(c)}	4 x 10 ⁻³
15	Ash removal system (not operative during processing)			
15A	Ash	23,000 kg/yr (100 m ³ /yr)	1.0	1.0
15B	Transport air	8.5 m ³ /min	0	0
15C	Filtered air	8.5 m ³ /min	1 x 10 ⁻⁸	1 x 10 ⁻⁸
16	Secondary chamber propane supply	0-1 m ³ /min (STP)	0	0
17	Secondary chamber air supply	1.4-15 m ³ /min (STP)	0	0
18	Incinerator off-gas	10-32 m ³ /min (STP)	4 x 10 ⁻³ 1 x 10 ^{-3(c)}	4 x 10 ⁻³

a. Fraction of input activity (Table 4.2.21)

b. Based on 4300 hr/yr of incinerator operation

c. Volatile ruthenium species only; see rest of listing for particulate ruthenium.

The operation of the ash collection subsystem is identical to that described in Section 4.4.1.3 except that the ash is vacuumed through a glove box-enclosed, lower chamber door instead of by manipulators in a shielded cell.

Off-gas Treatment. The off-gas treatment operation for the LLW incineration facility is identical to that discussed in Section 4.4.1.3. The flow diagram and stream data for the LLW incinerator off-gas treatment system are given in Figure 4.4.17 and Table 4.4.24.

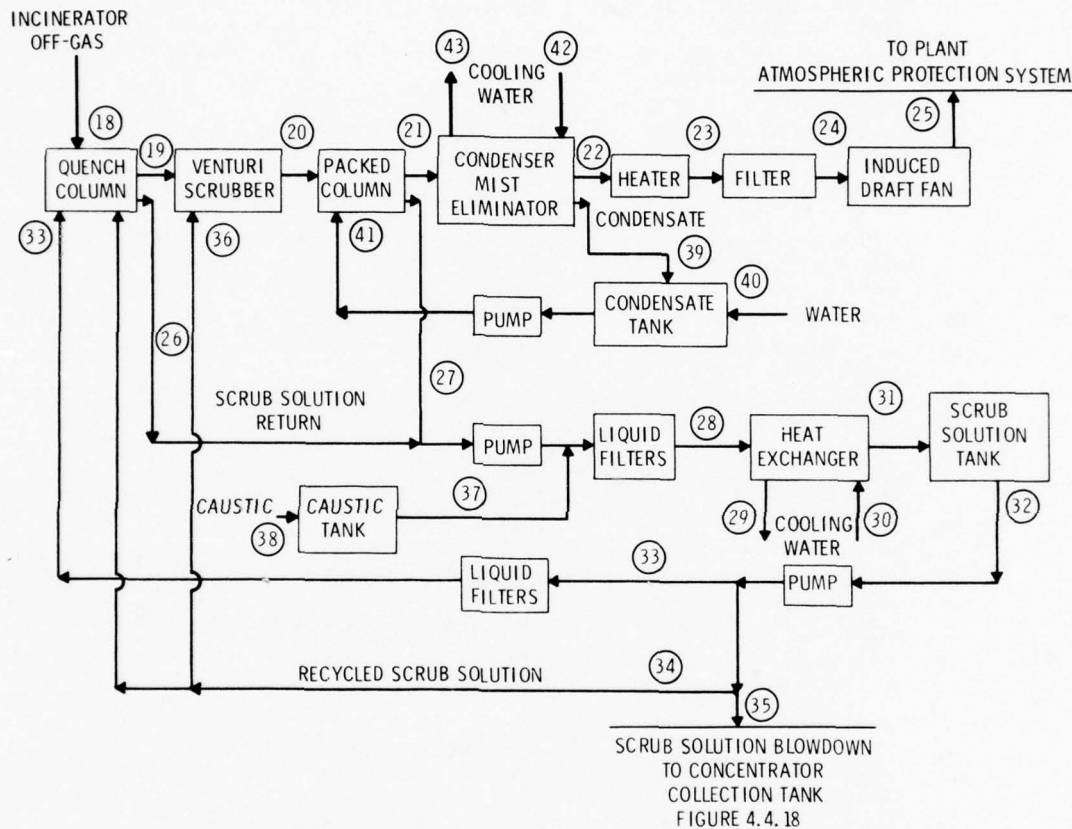


FIGURE 4.4.17. Off-gas Treatment Flow Diagram for the Fuel Reprocessing Plant LLW Incineration Facility (Circled numbers refer to stream numbers given in Table 4.4.24.)

Scrubbing Solution Recycle. Scrubbing solution recycle operation is identical to that described in Section 4.4.1.3. The flow diagram and stream data for the LLW recycle subsystem are included in Figure 4.4.17 and Table 4.4.24.

Scrubbing Solution Concentration. The scrubbing solution blowdown from the LLW incineration facility is routed to the concentrator, a part of the ILW incineration facility (Section 4.4.1.3), where it is concentrated along with the scrub solution from the ILW facility. The concentrator flowsheet and stream data are given in Figure 4.4.18 and Table 4.4.25. These show only the contribution to this concentrator attributable to the LLW; the flow rates are based on 4300 hr/yr operation on LLW scrub solution concentration.

TABLE 4.4.24. Off-gas Treatment Stream Flow Data for the Fuel Reprocessing Plant LLW Incineration Facility

Stream Number	Description	Rate ^(b)	Radioactivity Factors ^(a)	
			Fission Products	Actinides
18	Incinerator off-gas (1100°C)	10 - 32 m ³ /min (STP)	4×10^{-3} $1 \times 10^{-3(c)}$	4×10^{-3}
19	Quenched off-gas (77°C)	21 - 60 m ³ /min (STP)	1×10^{-3} $1 \times 10^{-3(c)}$	4×10^{-3}
20	Venturi scrubbed off-gas (particles removed)	21 - 60 m ³ /min (STP)	8×10^{-5}	8×10^{-5}
21	Packed column off-gas (65°C) (mineral acids removed)	21 - 60 m ³ /min (STP)	8×10^{-5}	8×10^{-5}
22	Condenser off-gas (50°C) (most of water removed)	11 - 32 m ³ /min (STP)	8×10^{-5}	8×10^{-5}
23	Superheated off-gas (60°C)	11 - 32 m ³ /min (STP)	8×10^{-5}	8×10^{-5}
24	Filtered off-gas	11 - 32 m ³ /min (STP)	8×10^{-12}	8×10^{-12}
25	Cleaned off-gas to plant atmospheric protection system	11 - 32 m ³ /min (STP)	8×10^{-12}	8×10^{-12}
26	Excess quench liquid return	90 - 106 ℓ /min	---	---
27	Venturi scrubber and packed column liquid return	87 - 132 ℓ /min	4×10^{-3}	4×10^{-3}
28	Neutralized scrub solution return after particle removal	174 - 238 ℓ /min	1×10^{-3}	1×10^{-3}
29	Scrub solution cooler, water supply (24°C)	795 ℓ /min	0	0
30	Scrub solution cooler, water return (32°C)	795 ℓ /min	0	0
31	Cooled scrub solution to hold tank (32°C)	174 - 238 ℓ /min	1×10^{-3}	1×10^{-3}
32	Scrub solution tank outlet	147 - 223 ℓ /min	1×10^{-3}	1×10^{-3}
33	Recycled scrub solution to quench column weir (filtered to remove additional particles)	68 ℓ /min	---	---
34	Recycled scrub solution to the quench column and venturi scrubber	102 - 148 ℓ /min	---	---
35	Scrub solution blowdown to concentrator collection tank (32°C)	5.7 ℓ /min	1×10^{-3}	1×10^{-3}
36	Venturi solution	57 - 102 ℓ /min	---	---
37	Caustic solution (20% NaOH) addition	0 - 3.8 ℓ /min	0	0
38	Solid caustic and water		0	0
39	Condensate return	11 - 23 ℓ /min	---	---
40	Scrubbing solution makeup water	3.8 - 30 ℓ /min	0	0
41	Condensate recycle to packed column	30 ℓ /min	---	---
42	Condenser cooling water supply (t_c)	570 ℓ /min	0	0
43	Condenser cooling water return ($t_c + 20^\circ$)	570 ℓ /min	0	0

a. Fraction of input activity (Table 4.4.21)

b. Based on 4300 hr/yr of incinerator operation

c. Volatile ruthenium species only; see rest of listing for particulate ruthenium.

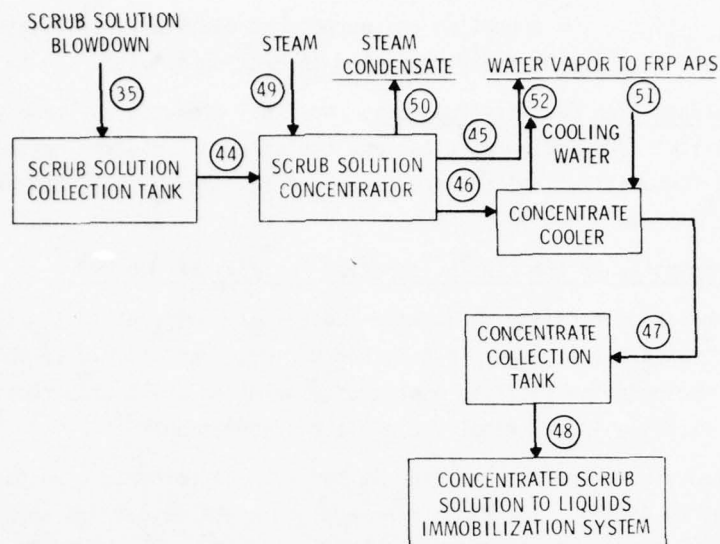


FIGURE 4.4.18. Scrubbing Solution Concentration Flow Diagram for the Fuel Reprocessing Plant LLW Incineration Facility (Circled numbers refer to stream numbers given in Table 4.4.25.)

TABLE 4.4.25. Scrubbing Solution Concentration Stream Flow Data for the Fuel Reprocessing Plant LLW Incineration Facility

Stream Number	Description	Rate ^(b)	Radioactivity Factors ^(a)	
			Fission Products	Actinides
35	Scrub solution (32°C)	5.7 l/min	1×10^{-3}	1×10^{-3}
44	Concentrator feed	5.7 l/min	1×10^{-3}	1×10^{-3}
45	Water vapor (to plant APS)	5.9 m ³ /min (STP)	1×10^{-8}	1×10^{-8}
46	Concentrator bottoms (~100°C)	0.9 l/min	1×10^{-3}	1×10^{-3}
47	Cooled concentrator bottoms (38°C)	0.9 l/min	1×10^{-3}	1×10^{-3}
48	Concentrated liquids to immobilization system	0.9 l/min (2.2×10^5 l/yr)	1×10^{-3}	1×10^{-3}
49	Steam	6 kg/min (1.6×10^6 kg/yr)	0	0
50	Condensate return	6 kg/min	0	0
51	Cooling water (t_c)	3.4 l/min	0	0
52	Cooling water return ($t_c + 15^\circ\text{C}$)	3.4 l/min	0	0

a. Fraction of input activity (Table 4.4.21)

b. Based on 4300 hr/yr of incinerator operation.

Auxiliary Utilities. The operation and purpose of auxiliary utilities in the LLW incineration facility are the same as those described in Section 4.4.1.3.

Low-Level Incineration Facility Products. No final products are produced in the LLW incineration facility. The incinerator ash and the scrubber solution concentrate require further treatment (immobilization) and are therefore included as secondary wastes (Section 4.4.2.6).

4.4.2.4 Description of the LLW Incineration Facility at the FRP

The LLW incineration facility is located immediately adjacent to the ILW incineration facility (see Section 4.4.1.4, Figure 4.4.6) and differs from it only in shielding requirements. Whereas, the ILW incineration facility uses mostly shielded cells with remote operation, the LLW incineration facility is principally a glove box operation.

The controlled-air incineration system is housed in a concrete structure approximately 27.4 by 13.7 m (90 by 45 ft). The floor plan and equipment layout are shown in Figures 4.4.19 and 4.4.20. The processing area, 12 m wide by 16 m long by 7.6 m high (40 x 53 x 25 ft), houses the incinerator, ash removal and packaging equipment, and the off-gas treatment system, as well as the instrumentation and control systems required to operate the process. The off-gas treatment area is provided with a stainless steel floor pan which drains to a sump to collect liquid drainages, leakages, and decontamination liquids. Adjacent to the processing area, the waste receiving and feed preparation area is a 16.5 x 13.4 m (54 x 44 ft) room which encloses the incinerator feed glove box train and storage area for untreated waste.

The LLW incineration facility is constructed of reinforced concrete to withstand design-basis natural phenomena, including earthquakes and tornadoes, and to prevent penetration by a maximum credible fire and/or explosion. The facility is designed to meet Category I structural requirements.

Although the overall layout of the LLW incineration facility is similar to that of the ILW facility discussed in Section 4.4.1.4, the equipment is located in a series of interconnected glove boxes rather than a series of interconnected shielded cells. Movement of the waste through the feed preparation and assay systems is by hand with the help of roller conveyors in the glove boxes. The ash is also vacuumed from the incinerator and is packaged by hand through glove box enclosures.

Equipment. The x-ray scanner, feed shredder, assay equipment, ram feeder, incinerator, entire off-gas treatment train, and scrubbing solution recycle equipment are identical to those discussed in Section 4.4.1.4. The LLW facility does not have filter compaction equipment since it does not receive filters.

Shielding and Remote Handling Equipment. Shielding is required at specific locations in the facility because of fission products and fissile material radiation from the radioactive waste. All glove boxes used in the facility are provided with appropriate thicknesses of gamma and neutron shielding in accordance with the expected radiation levels. Glove box gloves are of the leaded type at most locations. The incinerator is surrounded by shielding walls. The treated waste storage bin and the drums employed for ash transport are also adequately shielded for both gamma and neutron radiation.

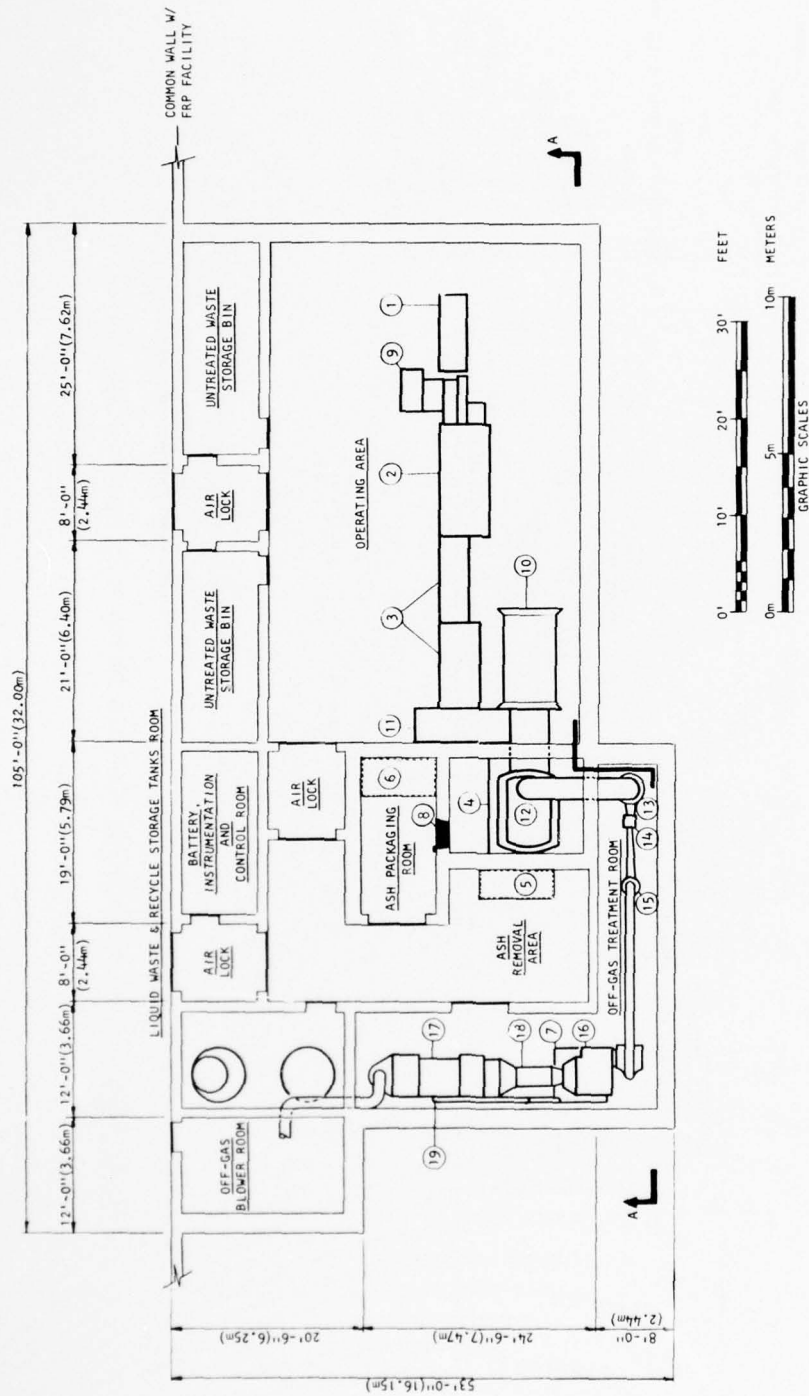


FIGURE 4.4.19. Fuel Reprocessing Plant LLW Incineration Facility, General Plan

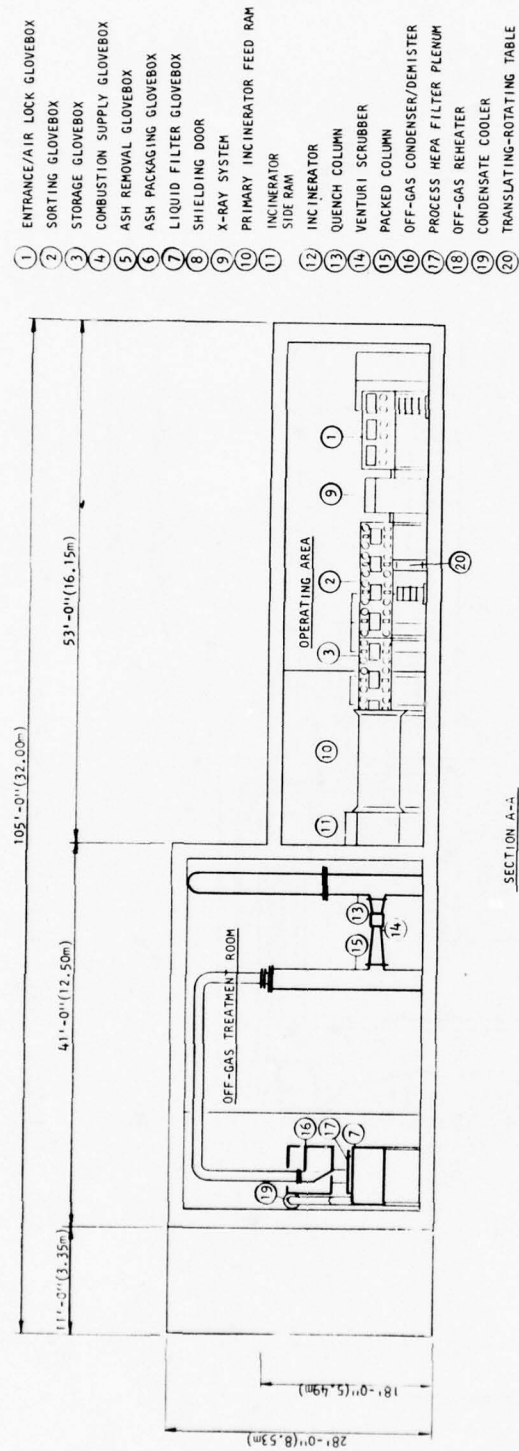


FIGURE 4.4.20. Fuel Reprocessing Plant LLW Incineration Facility, Section A-A

4.4.2.5 Operating and Maintenance Requirements for the LLW Incineration Facility at the FRP

Operating and maintenance requirements for the LLW incineration facility are generally the same as those of the ILW incineration facility (Section 4.4.1.5) except for the variations resulting from different shielding requirements and some difference in volume of material processed per year.

Facility Operation. Operation of the incinerator is semicontinuous with cool-down for ash removal every 60 to 100 hours, as discussed in greater detail in Section 4.4.1.5. About 4300 hours of actual incinerator operation are required per year, allowing adequate time for maintenance and for much of the feed preparation to be done during nonoperating periods.

Most of the operations, such as glove box load-in and load-out, feed preparation and transfer within the glove boxes, ash removal and packaging, and normal maintenance and replacement activities, are carried out manually by using glove box gloves. Otherwise, the facility operation is the same as that discussed in Section 4.4.1.5.

Maintenance. Maintenance requirements for the LLW incineration facility are similar to those of the ILW incineration facility (Section 4.4.1.5) but are somewhat simpler because of the lower shielding requirements. Since the LLW facility does not have the manipulators and cranes present in the ILW facility, maintenance on these is eliminated. Maintenance of items such as feed preparation equipment is easier in the glove box operation of the LLW incineration facility than in the shielded cell of the ILW incinerator. As in the ILW incineration facility, the primary and secondary incinerator chambers are expected to require changing every ten years; other major items are designed for the FRP lifetime.

Staffing. Staffing requirements for the LLW incineration facility are expected to be identical to those of the ILW incineration facility as presented in Section 4.4.1.5, Table 4.4.7. The somewhat greater ease of operation and maintenance of the less heavily shielded LLW incinerator compensates for the greater number of operating hours per year at the LLW incineration facility.

Supplies and Utilities. Table 4.4.26 shows the supplies used in the LLW incineration facility operation. Table 4.4.27 lists utilities required for the reference facility.

TABLE 4.4.26. Supply Requirements for the Fuel Reprocessing LLW Incineration Facility

Supply	Use	Annual Requirement
NaOH	pH control in off-gas scrubbing solution	3×10^4 kg
Cardboard boxes	Repackaging of sorted and shredded waste to be incinerated	5300

TABLE 4.4.27. Utility Requirements for the Fuel Reprocessing Plant LLW Incineration Facility

Utility	Use Rate	Annual Requirement ^(a)
Electricity	800 kW	3.4×10^6 kWh
Propane	15 m ³ /hr	6.5×10^4 m ³ (STP)
Steam	360 kg/hr	1.5×10^6 kg
Air	1.3×10^3 m ³ /hr	5.6×10^6 m ³
Water consumed	2.2 m ³ /hr	9500 m ³

a. Based on operation for 4300 hr/yr.

4.4.2.6 Secondary Radioactive Wastes from the LLW Incineration Facility at the FRP

Secondary radioactive wastes produced by the LLW incineration facility are shown in Table 4.4.28. The bases for determining the secondary waste volumes and activities shown in Table 4.4.28 are the same as those discussed in Section 4.4.16 for the ILW incineration facility. The composition of the scrubbing solution concentrate from the LLW incineration facility operation is the same as that produced by concentration of the ILW scrub solution shown in Table 4.4.13 except for the absence of Na₂HPO₄ in the LLW scrubber concentrate. The volume and activity of the LLW scrubber concentrate shown in Table 4.4.28 reflect only that portion of the overall concentrate contributed by LLW incineration.

The noncombustible general trash and failed equipment shown in Table 4.4.28 include the annual fraction of the incinerator primary and secondary chamber replacement which is expected to occur about every 10 years. Combustible general trash, including scrub solution recycle filters, is immediately recycled to the incineration process.

4.4.2.7 Emissions from the LLW Incineration Facility at the FRP

Facility emissions are shown in Table 4.4.29. The activity levels in the gaseous emissions are based on the same estimates as those made for the ILW incineration facility discussed in Sections 4.4.1.6 and 4.4.1.7. The values in Table 4.4.29 are considered conservative for the reasons discussed in Sections 4.4.1.6 and 4.4.1.7.

An estimate of the integrated annual release due to minor accidents (Section 4.4.2.9) for this facility is included in Table 4.4.29. It was developed by weighing the minor accident releases by their expected frequencies and summing the quantities for all identified minor accidents. In addition, a contingency was included in the integrated release to account for unidentified minor accidents and to compensate for the uncertainty in expected frequency information.

TABLE 4.4.28. Secondary Radioactive Wastes from the Fuel Reprocessing Plant LLW Incineration Facility

Description ^(a)	Annual Volume, m ³ /yr	Radioactivity Factor ^(a)
Incinerator ash	100	All radionuclides 1.0
Scrubbing solution concentrate	220	All radionuclides 1×10^{-3}
Noncombustible general trash and failed equipment	2	Fission products 1×10^{-3} Actinides 1×10^{-4}
Combustible and Compactable Waste	40	All radionuclides 1×10^{-6}

a. Fraction of input activity (shown in Table 4.4.21) in secondary wastes.

TABLE 4.4.29. Emissions from the Fuel Reprocessing Plant LLW Incineration Facility

Emission	Description	Annual Quantity	Radioactivity Release Factor to Atmosphere ^(a)
Gaseous	Cleaned incinerator off-gas	Air 6×10^6 m ³	All 8×10^{-16}
		HCl 100 kg	
		SO _x 180 kg	
		NO _x 400 kg	
		CO 190 kg	
	Water evaporated from spent scrubber solution	H ₂ O 1.2×10^6 kg	All 1×10^{-12}
	Minor accident integrated annual release		All 1×10^{-12}
Cooling Tower Water	Evaporated (T = 38°C)	7.9×10^6 kg	
	Drift (T = 38°C)	3.8×10^4 kg	
	Blowdown (T = 27°C)	1.4×10^6 kg	
Other	Heat		
	to cooling tower	5.3×10^3 MW-hr (1.8×10^{10} BTU)	
	in gaseous emission	1.8×10^3 MW-hr (6.1×10^9 BTU)	

a. Fraction of input activity (Table 4.4.21) released to the atmosphere. Released over 4300 hours/yr. Includes DF from main plant APS.

4.4.2.8 Decommissioning Considerations for the LLW Incineration Facility at the FRP

Decommissioning considerations for the LLW incineration facility are essentially identical to those discussed for the ILW incineration facility in Section 4.4.1.8. Decommissioning the LLW incineration facility would be easier than decommissioning the ILW facility because of the approximately 1000-fold lower activity levels and the lack of heavily shielded cells in the LLW facility.

4.4.2.9 Postulated Accidents for the LLW Incineration Facility at the FRP

Postulated minor and moderate accident scenarios for the LLW incineration facility are nearly the same as those discussed in Section 4.4.1.9. These scenarios are shown for the LLW facility in Tables 4.4.30 and 4.4.31. The consequences of the accidents are only slightly affected by the fact that the LLW incineration facility feed preparation is a glove box rather than a hot cell operation. The chief effect of this difference may be a somewhat greater hazard to operators if a fire or explosion in the feed preparation line occurs, but no significant effect on plant release is expected.

The cell enclosing the incinerator primary and secondary chambers is smaller in the LLW incineration facility than in the ILW facility; for this reason although not probable, an incinerator explosion could breach the cell filters in the LLW facility. If this occurred, the release from Accident 4.4.5 would be directly to the FRP's APS rather than to just the cell atmosphere. The probability of this occurring is estimated to be no more than one-tenth of the probability shown in Table 4.4.31 for Accident 4.4.5.

TABLE 4.4.30. Minor Accidents for the Fuel Reprocessing Plant LLW Incineration Facility

Accident No. and Description	Sequence of Events	Safety System	Release
4.4.1 — Loss of cooling water to incinerator off-gas treatment system; expected frequency, 0.05/yr.	<ol style="list-style-type: none"> 1. Cooling water flow to off-gas treatment system fails. 2. Humidity in off-gas rises. 3. HEPA filters slowly plug because of condensing moisture. 4. HEPA filter blockage shuts down system in about 30 minutes. 	<ol style="list-style-type: none"> 1. Slow blockage of air-flow (~30 min) allows adequate time for equipment shutdown. 2. A two-hour back-up supply of pressurized water to quench column prevents other effects of coolant loss from occurring. 	None
4.4.2 — Minor fire in feed protection system; expected frequency, 0.2/yr.	<ol style="list-style-type: none"> 1. Fire starts in trash in feed separation area. 2. Small fire is detected and extinguished. 	<ol style="list-style-type: none"> 1. Well-designed automatic fire suppression system 2. Additional manual operated fire suppression equipment. 	3×10^{-5} of radionuclides in total waste processed (Table 4.4.21) released to glove box atmosphere.

TABLE 4.4.31. Moderate Accidents for the Fuel Reprocessing Plant LLW Incineration Facility

Accident No. and Description	Sequence of Events	Safety System	Release
4.4.3 - Major fire in feed preparation line; expected frequency 0.01/yr.	<ol style="list-style-type: none"> 1. Feed preparation line contains maximum loading of waste (24 hr of incinerator feed). 2. Fire initiates in waste. 3. Fire suppression system does not operate. 4. Glove box atmospheric filters fail 	<ol style="list-style-type: none"> 1. Well-designed automatic fire suppression system would be used. 2. Additional manual or redundant automatic fire suppression equipment could be used. 3. Proper location of filters minimizes chance of flame caused filter breach. 	2.8×10^{-3} of radionuclides in total annual waste processed released directly to the FRP APS.
4.4.4 - Explosion in feed preparation line, expected frequency 0.02/yr.	<ol style="list-style-type: none"> 1. Small amounts of explosive in wastes. 2. Such material explodes during sorting operations. 	<ol style="list-style-type: none"> 1. Explosives or explosive chemicals are not used in FRP operation. 2. Waste form designed to prevent formation of explosive material. 	1×10^{-4} of radionuclides in total annual waste processed (Table 4.4.21) released to cell filters.
4.4.5 - Incinerator explosion; expected frequency, 0.01/yr.	<ol style="list-style-type: none"> 1. Flame-out occurs in incinerator. 2. Explosive reignition of propane-air mixture in incinerator causes breach of incinerator integrity. 3. 50% of ash in incinerator at maximum load is suspended in cell air. 	<ol style="list-style-type: none"> 1. Incinerator control system greatly reduces the probability of occurrence. 2. Automatic fire-control sprinklers would activate, lowering airborne particles. 	1.2×10^{-2} of radionuclides in total waste processed (Table 4.4.21) released to incinerator cell filters in 0.5 hours.

The bases for the release figures shown in Tables 4.4.30 and 4.4.31 are the same as those discussed in Section 4.4.1.9. No accidents that could be classified as severe accidents were postulated for this technology.

4.4.2.10 Costs for the LLW Incineration Facility at the FRP

Estimates have been made, in mid-1976 dollars, of capital, operating and leveled unit costs. A complete description of the cost estimate bases, assumptions and definitions is given in Section 3.8.

Capital Costs. The capital cost estimate shown in Table 4.4.32 covers all capital costs specifically resulting from inclusion of the LLW incineration facility as an integral part of the FRP (described in Section 3.2). These costs also include the effect of incremental additions to utilities supplies such as electrical, compressed air, heat, ventilation, and air conditioning (HVAC), and similar auxiliaries, as well as the cable, piping, and other

TABLE 4.4.32. Capital Cost Estimate for the Fuel Reprocessing Plant LLW Incineration Facility

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		4	850	50	900
Buildings and structures		42	390	500	890
Bulk materials		21	760	250	1010
Site improvements		—	—	—	—
Subtotal of direct site construction costs		67	2000	800	2800
Indirect site construction costs	18	13	300	400	700
Total field cost	18	80	2300	1200	3500
Architect-engineer services					700
Subtotal					4200
Owner's Cost					1300
Total facility cost					5500
Estimate accuracy range					±25%

bulk materials incorporated directly into the LLW incineration facility. However, general FRP costs for such services as laboratories, and warehousing are not allocated to the reference facility.

The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation with the exception of working capital and the cost of waste containers required to hold untreated waste packages (considered part of the FRP operating cost).

Operating Cost. The operating cost components for LLW incineration at the FRP are shown in Table 4.4.33. Direct labor costs are expected to be similar to those for ILW incineration and are based on manpower estimates given in Table 4.4.7. Process material and utility costs are derived from requirements given in Tables 4.4.26 and 4.4.27. Annual maintenance materials costs are estimated at three percent of initial major equipment costs. Overhead and miscellaneous costs are estimated using the standard method described in Section 3.8.

Levelized Unit Costs. Table 4.4.34 lists the total levelized unit cost, including the levelized capital and operating costs. The cost calculations assume private ownership of the facilities and a 15-year economic life.

TABLE 4.4.33. Operating Cost Estimate for LLW Incineration at the Fuel Reprocessing Plant

Cost Element	Annual Costs, \$1000s
Direct labor	210
Process materials	50
Utilities	80
Maintenance materials	25
Overhead	250
Miscellaneous	30
TOTAL	650 $\pm 50\%$ -25%

TABLE 4.4.34. Levelized Unit Cost Estimate for LLW Incineration at the Fuel Reprocessing Plant

Cost Element	Unit Cost, \$/kg HM
Levelized capital charge	.70
Levelized operating charge	.30
Levelized total unit cost	1.00 $\pm 35\%$

4.4.2.11 Construction Requirements for the LLW Incineration Facility at the FRP

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating this impact.

Project Schedules and Construction Manpower. The schedule for engineering, procurement and construction of the LLW incineration facility is an integral factor in the overall schedule for the construction phase of the FRP. The field labor force estimated for the construction of the LLW incineration facility is tabulated below:

	Man-hours, 1000s
Manual field labor	80
Nonmanual field labor	18
Total field labor	98

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials and services provided at the site of the FRP while offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories follows:

	Costs, \$1000s
Onsite	1500
Offsite	4000
Total	5500

Site Requirements. No additional site requirements beyond those for the FRP are identifiable for the LLW incineration facility. Land commitments for the facility are included with those of the FRP.

Water. Approximately 1100 m^3 (0.3×10^6 gal) of water are required during the construction period.

Construction Materials. Materials committed to the facility are:

Concrete	500 m^3	(700 yd^3)
Steel	90 MT	(100 tons)
Copper	0.9 MT	(1 ton)
Zinc	negligible	negligible
Aluminum	negligible	negligible
Lumber	25 m^3	(10 MFBM)

Energy. Energy resources used during construction are:

Propane	11 m^3	(3,000 gal)
Diesel fuel	110 m^3	(30,000 gal)
Gasoline	76 m^3	(20,000 gal)
Electricity:		
Peak demand		120 kW
Total consumption		60,000 kWh

Transportation Requirements. No separate transportation requirements for the LLW incineration facility have been identified beyond those for the FRP.

4.4.2.12 Effects of Fuel Cycle Options on LLW Incineration at the FRP

The reference process for incineration of LLW at an FRP assumes reprocessing of LWR fuel and recycling the recovered uranium and plutonium. The following alternative fuel cycle modes have also been assessed insofar as they relate to incineration of LLW at an FRP.

No Recycle. The no recycle option eliminates the FRP; LLW is not generated and incineration is not required.

Uranium Recycle Only with Plutonium to a Repository. For uranium recycle only, with plutonium sent to a repository, the LLW incineration facility design and operation would be virtually the same as in the case of uranium and plutonium recycle.

Uranium Recycle Only with Plutonium to the HLW. In the case of uranium recycle only, with plutonium to the HLW, the LLW incineration facility design and operation would also be virtually the same as in the reference case.

4.4.3 Compactable and Combustible ILW Packaging Without Treatment at the Fuel Reprocessing Plant

The nuclear industry has accumulated many years of experience in handling compactable and combustible wastes by packaging without treatment. This method is considered an alternative to the incineration of ILW, the reference process discussed in Section 4.4.1. With packaging without treatment, intermediate-level waste is neither compacted nor incinerated prior to final packaging. Instead, the waste (already sealed in plastic bags) is packaged in plastic bag-lined drums for storage and/or shipment to a waste repository. Because of the activity level of the ILW, the packaging and storage operations are conducted remotely in shielded facilities.

4.4.3.1 Alternatives for ILW Packaging Without Treatment at the FRP

Since packaging without treatment implies a minimal process operation, alternatives are confined to variation in the sequence of events. For example, the degree to which waste is packaged in drums at the source of waste generation as opposed to at a central packaging facility can vary. The waste can be brought to the central facility in special reuseable shielded transport containers, from which it is transferred to final 55-gal (or 80-gal) steel drums; or, it may be brought already in the drums, which are themselves contained in an outer gamma shield. In the latter case, the operation would consist only of sealing, surveying, assaying, and, if needed, decontaminating the outsides of the drums. The location of the assaying step is also a possible variable. Assaying would most likely be done on the drummed waste, but could be done on a special hopper of bagged waste at another point in the flow scheme.

The facility for packaging without treatment described here provides the capability for receiving the waste, which is packaged in plastic bags, in a special waste receptacle; transferring this waste to an assay container; and, after assaying, transferring this waste to the 55-gal drums. If the incoming waste were in shielded 55-gal drums, and if assaying were done in the same drum, transfer of the waste would be necessary only in the case of damaged drums or drums with extensive external contamination.

4.4.3.2 Design Basis of the Facility for ILW Packaging Without Treatment at the FRP

The following assumptions were made in design of the facility for ILW packaging without treatment:

- The reference facility is associated with the operation of the reference 2000-MTHM fuel reprocessing plant (FRP). The supporting facilities and services are provided by the reprocessing plant.

4.4.60

- The packaging facility receives 1420 m^3 of TRU-contaminated combustible trash and 320 m^3 of TRU-contaminated ventilation filters per year. The 1420 m^3 of waste include that portion of the combustible trash from the main FRP that has a reading of $>200 \text{ mR/hr}$ in 55-gal drums, all the combustible trash from the PuO_2 conversion part of the plant, and the combustible trash (secondary wastes) produced by all the other waste treatment facilities directly associated with the FRP. About 10% of the total waste routed to this facility is expected to have relatively low dose rate readings. The 320 m^3 represent the entire volume of ventilation filters produced at the FRP and associated facilities. Table 4.4.1, with ion exchange resins and degraded extractants excluded, defines the sources, composition, and amounts of the waste to be received at this facility. Table 4.4.35 gives the annual quantities of major radionuclides in the waste.
- This facility is designed to package and ship approximately 2400 m^3 ($83,000 \text{ ft}^3$) per year of intermediate-gamma-activity-level contaminated waste.
- General trash is packaged into 55-gal DOT-17c drums, and HEPA filters are packaged into 80-gal drums; the estimated waste volumes require about 7200 55-gal drums and 2900 80-gal drums per year.
- The assay system provides for inventory control of fissile materials.
- Preshipment storage capacity is provided for three months of output to compensate for fluctuations in waste generation rate, shipping schedules, and similar factors. Storage space for incoming waste is also provided.
- The design provides a minimum of three levels of confinement and includes an internal truck bay to meet the confinement requirements for shipping operations.

4.4.3.3 ILW Packaging Without Treatment Process at the FRP

Figure 4.4.21 is a flow diagram showing the sequence of operations for the facility for ILW packaging without treatment. Table 4.4.36 characterizes the packaged waste leaving the facility. Since there is no release of activity, the activity of the drummed waste is equal to that of the feed.

Drums containing waste in sealed plastic bags are received at the facility for ILW packaging without treatment. A retractable hood is sealed against the waste carrier, and the drum is opened, and inspected. If the drum contains inappropriate materials such as liquids, they are removed. Questionable waste and waste in damaged drums is unloaded for further inspection and/or transferred to new drums. If the drum meets inspection, it can either be assayed directly, or the waste can be transferred to a separate assay container.

TABLE 4.4.35. Radionuclide Content of Wastes Handled in the Facility for ILW Packaging Without Treatment (a)

Source	Volume, m ³ /yr	Fission Product Content, Ci/yr										
		³ H	¹²⁹ I	⁹⁰ Sr + ⁹⁰ Y	⁹⁵ Zr + ⁹⁵ Nb	¹⁰⁶ Ru + ¹⁰⁶ Rh	¹³⁴ Cs + ¹³⁷ Ba	¹⁴⁴ Ce + ¹⁴⁴ Pr	All Other Fission Products			
Primary Waste												
Main plant combustible trash	800	0	0	2.4 x 10 ²	2.2 x 10 ¹	7.6 x 10 ²	6.0 x 10 ²	9.6 x 10 ²	2.0 x 10 ²			
Main plant ventilation filters	280	0	0	2.4 x 10 ³	2.2 x 10 ²	7.6 x 10 ³	6.0 x 10 ³	9.6 x 10 ³	2.0 x 10 ³			
PuO ₂ conversion facility combustible trash	60	0	0	0	0	0	0	0	0			
PuO ₂ conversion facility ventilation filters	40	0	0	0	0	0	0	0	0			
Secondary Waste												
Combustible trash	560	5.9 x 10 ⁻¹	7.0 x 10 ⁻⁴	4.8 x 10 ¹	4.4 x 10 ⁰	1.5 x 10 ²	1.2 x 10 ²	1.9 x 10 ²	4.0 x 10 ¹			
TOTAL	1766	5.9 x 10 ⁻¹	7.0 x 10 ⁻⁴	2.7 x 10 ³	2.4 x 10 ²	8.5 x 10 ³	6.7 x 10 ³	1.1 x 10 ⁴	2.2 x 10 ³			
Activation Products, Ci/yr												
Actinide Content, Ci/yr												
Other Plutonium												
239Pu	7.2 x 10 ⁻¹	241Pu	3.5 x 10 ²	1.2 x 10 ¹	3.4 x 10 ¹	0	0	0	0			
Actinides												
232Th	7.2	235U	3.5 x 10 ³	1.2 x 10 ²	3.4 x 10 ²	0	0	0	0			
Other Actinides												
238U	3.6 x 10 ²	239Pu	1.8 x 10 ⁵	6.2 x 10 ³	0	0	0	0	0			
Other Actinides												
240Pu	1.4 x 10 ³	241Pu	7.0 x 10 ⁵	2.5 x 10 ⁴	0	0	0	0	0			
Other Actinides												
242Cm	5 x 10 ⁻³	243Cm	2.5 x 10 ⁰	3.4 x 10 ⁻²	6.8 x 10 ⁰	8.2	8.2	3.4 x 10 ⁻¹	8.0			
Other Actinides												
244Cm	1.8 x 10 ³	245Cm	8.8 x 10 ⁵	3.1 x 10 ⁴	3.7 x 10 ²	8.2	8.2	3.4 x 10 ⁻¹	8.0			

a. Based on waste characterization Table 3.3.33 and secondary waste Table 3.5.1, assuming uranium and plutonium recycle, 2000 MTHM/yr reprocessed 1.5 years out of reactor.

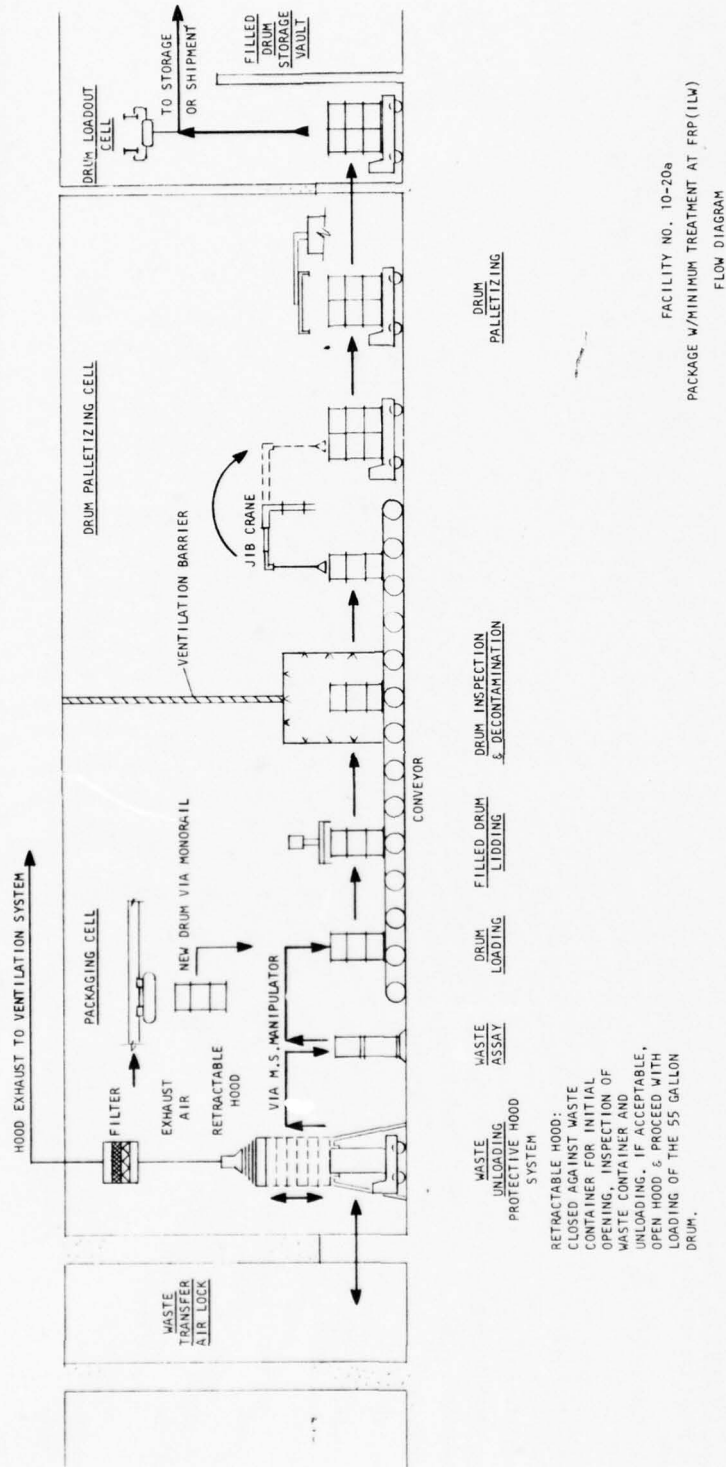


FIGURE 4.4.21. Flow Diagram for ILW Packaging Without Treatment at the Fuel Reprocessing Plant

TABLE 4.4.36. Packaged Wastes from the Facility for ILW Packaging Without Treatment at the Fuel Reprocessing Plant

Surface Dose Rate	Volume, (a) m ³ /yr	Density, kg/m ³	Ratio of Treated Volume(a) to Untreated Volume	Drums/yr		Radioactivity as Fraction of Input(b)
				55-gal	80-gal	
0.2-1.0 R/hr	150	120	1.05	720		<u>Fission Products</u> $^3\text{H} = 1.0$ $^{129}\text{I} = 1.0$ All others = 1.1×10^{-3} <u>Actinides</u> Pu = 0.2 All others = 0.016 <u>Activation Products</u> All = 1.0
1-10 R/hr	1350	120	1.05	6480		<u>Fission Products</u> $^3\text{H} = 0$ $^{129}\text{I} = 0$ All others = 0.11 <u>Actinides</u> Pu = 4×10^{-4} All others = 0.09 <u>Activation Products</u> All = 1×10^{-2}
>10 R/hr	875	160	2.74		2900	<u>Fission Products</u> $^3\text{H} = 0$ $^{129}\text{I} = 0$ All others = 0.89 <u>Actinides</u> Pu = 0.8 All others = 0.9 <u>Activation Products</u> All = 0

a. Treated volume based on container volume.

b. Fraction of total input to the facility (Table 4.4.35).

The waste is assayed to determine fissile material content. If assayed in drums, the drums move on by conveyer to the lidding station; if not, the waste parcels are removed from the assay container, the general trash is placed in plastic-lined, 55-gal drums, and the HEPA filters are placed in plastic-lined, 80-gal drums. The 80-gal drums hold one 61 x 61 x 30.5-cm filter. Although not done in the process described here, the remaining space could be filled with parcels of general trash. The drums then progress by conveyer to a lidding station where

automatic equipment caps them. Next, the drums pass through a final inspection and decontamination station and are palletized (four drums per pallet) by automatic equipment. They are then removed to the shielded storage area or to the truck bay for shipment. The drummed waste is sent either to interim storage or the repository.

4.4.3.4 Description of the Facility for ILW Packaging Without Treatment at the FRP

The facility for the ILW packaging without treatment is located in the same area within the FRP as the ILW incineration facility (see Figure 4.4.6). The facility covers approximately 950 m^2 ($10,000 \text{ ft}^2$) and houses the waste packaging cell, drum palletizing cell, untreated waste storage area, operating station, new pallet supply storage area, the drum handling crane, an internal truck bay, and a shielded area for storage of about 1900 filled drums. The building and equipment arrangements are shown on Figures 4.4.22 through 4.4.25. The drum handling bridge crane is operated remotely from the shielded operating aisle spanning the facility at an elevation of 2.3 m (7.5 ft) from the operating area floor. Part of the waste packaging cell and the drum palletizing cell are below grade level, with depths of 1.5 m and 2.9 m (5 ft and 9.5 ft), respectively. A shielding gate, running the full width of the facility, which can be raised to allow passage of the bridge crane, is installed to reduce radiation scatter from the storage area to the operating area as well as the truck bay. During truck loading operations, the truck bay is cleared of personnel and the shielding gate is raised. As a result, the truck bay becomes a remotely-operated facility. The facility service requirements, such as for light, power, heat, and ventilation, are integrated with the FRP services. The facility structure is of reinforced concrete to withstand design-basis natural phenomena, including earthquakes and tornadoes, and to prevent penetration by a maximum credible fire and/or explosion. The reference facility is designed to meet Category I structural requirements.

Waste Unloading System. The waste unloading system (WUS) is equipped with a retractable, telescopic hood that seals against the waste container in the down position. This system is connected to a HEPA filtration system. The waste unloading system is designed to prevent spread of contamination when a drum containing damaged or penetrated waste packages is opened and the waste packages are unloaded.

Drum Capping and Palletizing. Fully automatic equipment is used to cap and palletize filled drums. Four filled drums are bound on each pallet for shipment and/or storage.

Facility Decontamination. A conventional, remotely-operated, water-type sprinkler system is installed so that a decontaminating solution can be sprayed into the cell of the facility to remove surface contamination in the event of an abnormal occurrence. The waste solution is drained to a floor sump, from which it is pumped to the liquid waste system of the FRP.

Fire Protection System. The facility is protected by a wet-pipe sprinkler system, except for the drum loading station, which is equipped with a chemical fire suppressant system. This system provides a total flooding of 10 seconds discharge with a minimum of 5% concentration and a 3-minute soak time.

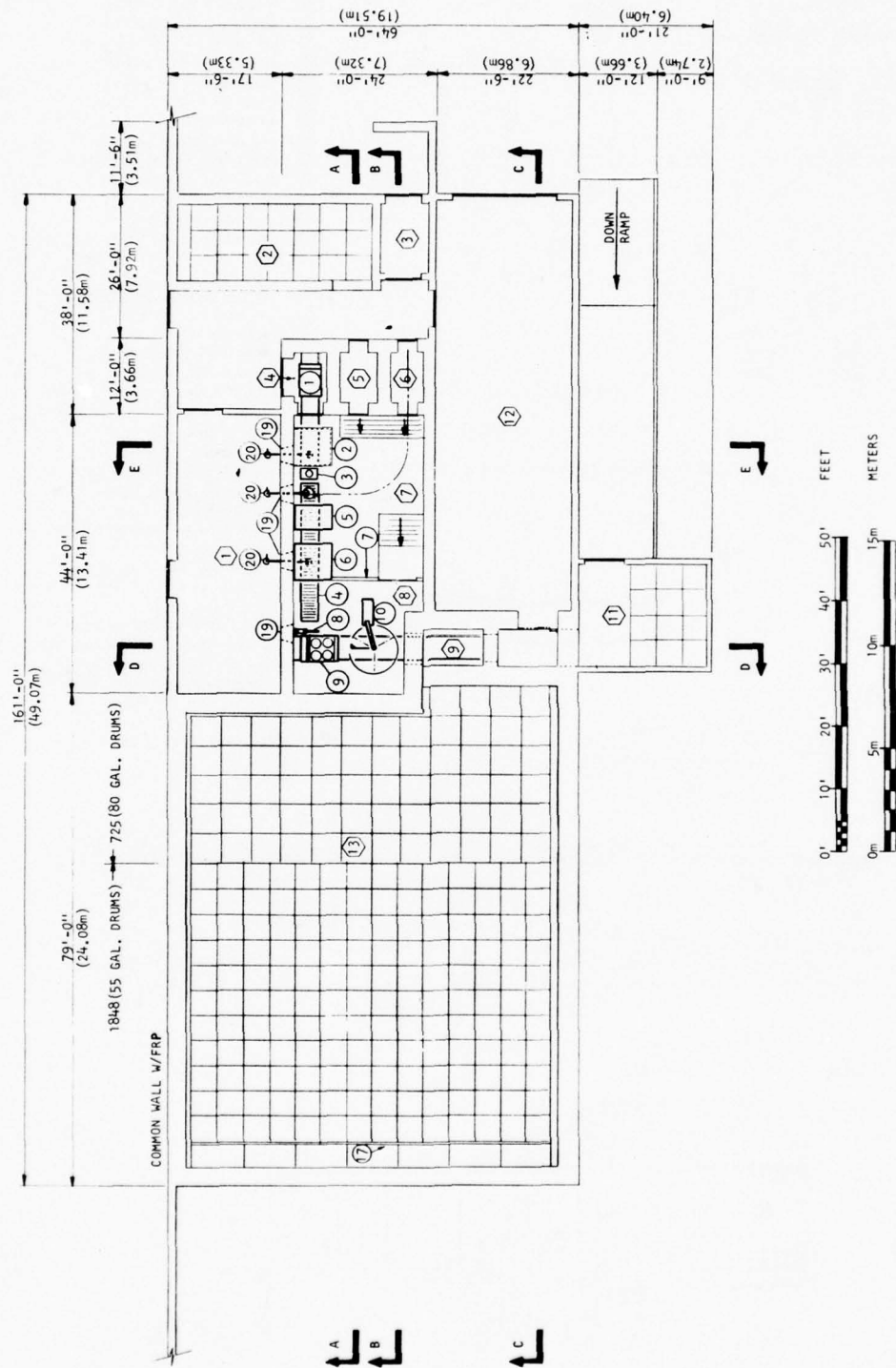


FIGURE 4.4.22. Facility for ILW Packaging Without Treatment at the Fuel Reprocessing Plant, General Plan at Grade (see Figure 4.4.23 for number key.)

4.4.66

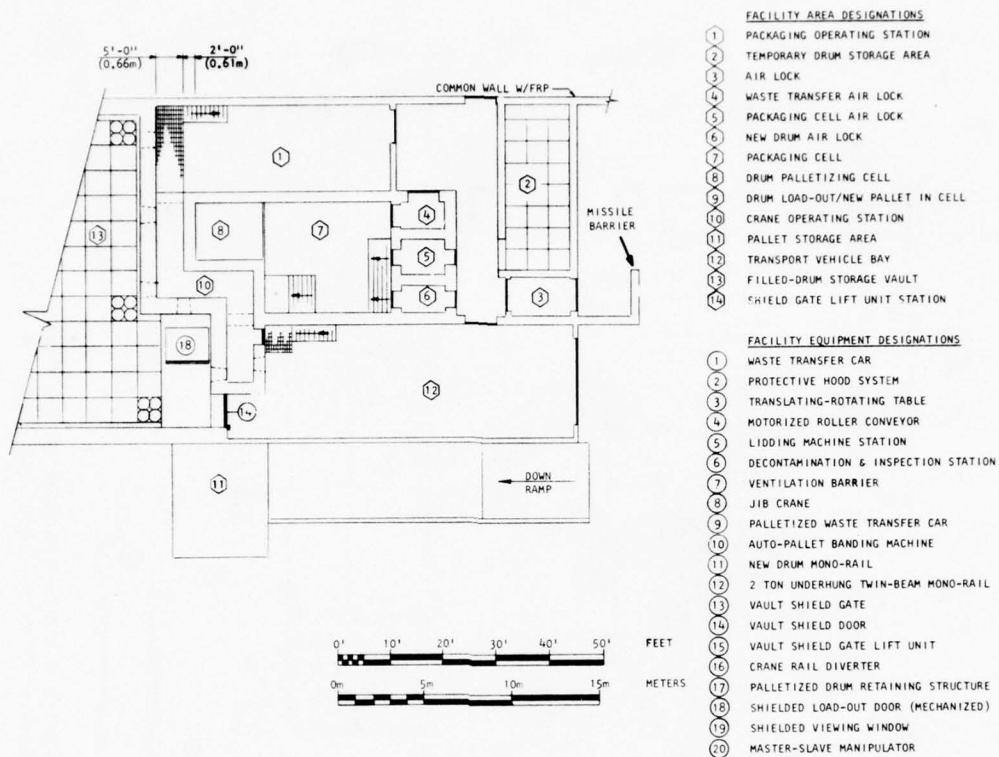


FIGURE 4.4.23. Facility for ILW Packaging Without Treatment at the Fuel Reprocessing Plant, Partial of Upper Plan

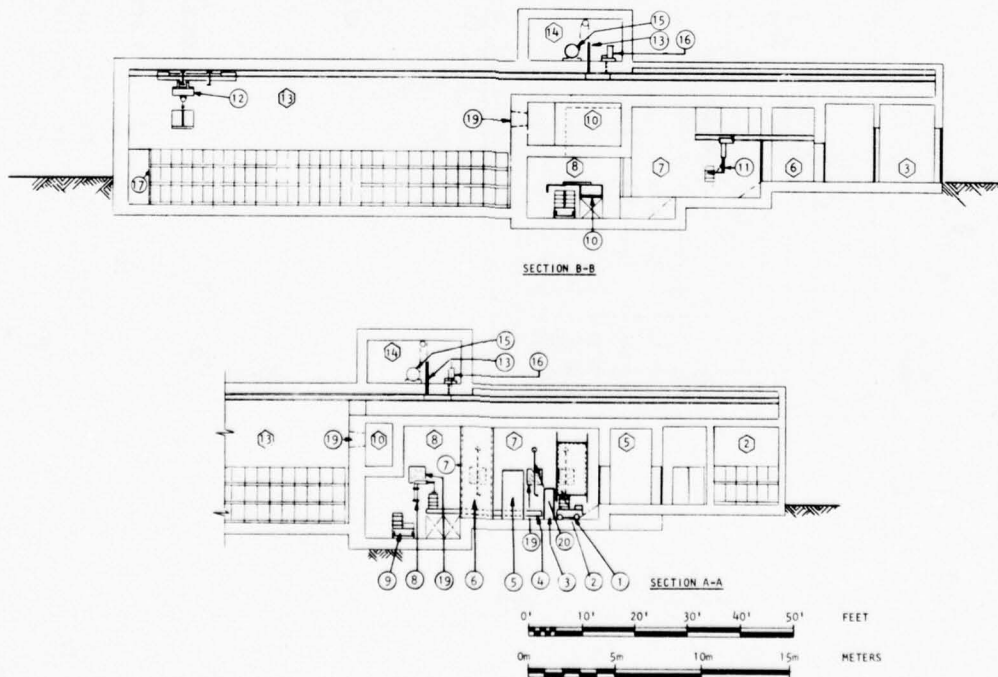


FIGURE 4.4.24. Facility for ILW Packaging Without Treatment at the Fuel Reprocessing Plant, Sections A-A, B-B (See Figure 4.4.23 for number key.)

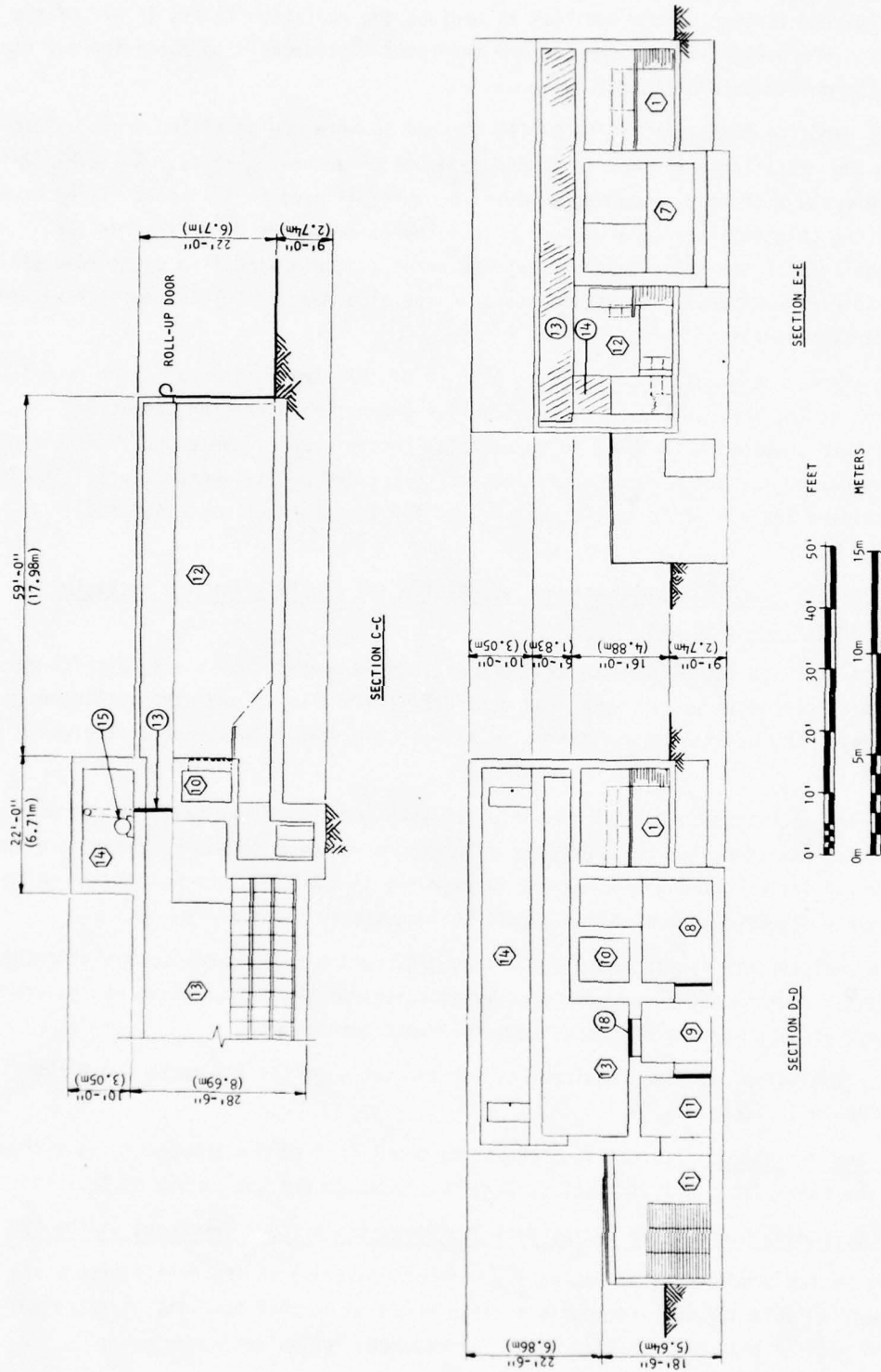


FIGURE 4.4.25. Facility for ILW Packaging Without Treatment at the Fuel Reprocessing Plant, Sections C-C, D-D, E-E (See Figure 4.4.23 for number key.)

Radiation Monitoring System. Beta-gamma, alpha, and neutron radiation area monitors are strategically located throughout the facility to monitor the radiation levels in all of the operating areas. Representative air samples are monitored continuously to check for any contamination in the operating and storage areas.

Waste Drum Handling Equipment. A fork-lift is used to move new or filled drums within the processing and operating areas and to transport drums of untreated waste. A 1.8-MT (2-ton) overhead bridge crane with bridge-mounted television camera is used to transport filled drum pallets inside the shielded storage area and to move the filled drums directly from the shielded storage area to the truck transports. The crane is controlled from a shielded aisle provided with shielding windows. Television cameras are also mounted inside the storage area to aid drum transfer operation.

Shielding and Remote Handling Equipment. Because of the penetrating radiation from ILW wastes generated at the FRP, shielding is required for the entire packaging operation. Operating cells are shielded with 60-cm to 90-cm thick concrete walls. Shielded viewing windows are provided as needed for the various operations to be carried out by manipulators. Shielded transport containers and fork-lift trucks can be used for transport of waste outside of the cells.

4.4.3.5 Operating and Maintenance Requirements for the Facility for ILW Packaging Without Treatment at the FRP

The facility for ILW packaging without treatment can be operated on a single shift per day or multi-shift operation as the work load demands; it can also be operated continuously or intermittently. The operations are scheduled to meet the need established by the waste generation rate.

The packaging operation is carried out in a remotely-controlled hot-cell. Minor maintenance is carried out remotely, but any major maintenance requires personnel entry into the cell. Since very little contamination spread is expected in the cell, removal of the waste inventory and very simple decontamination should be adequate to allow entry.

No special maintenance requirements are expected since the cell is equipped with rather simple equipment. Routine maintenance is usually adequate for the master-slave manipulators, overhead cranes, etc., which are standard items in remote operations.

Staffing. Estimated staffing requirements for the facility for ILW packaging without treatment are shown in Table 4.4.37.

Supplies and Utilities. Table 4.4.38 shows the supplies used for ILW packaging without treatment at the FRP. Table 4.4.39 lists utility requirements for the packaging facility.

4.4.3.6 Secondary Radioactive Wastes from ILW Packaging Without Treatment at the FRP

Secondary wastes produced by packaging ILW without treatment at the fuel reprocessing plant are shown in Table 4.4.40. Combustible trash produced in this facility is packaged along with the rest of the waste processed and is accounted for as secondary waste in the feed to the facility (Table 4.4.1).

TABLE 4.4.37. Staffing Requirements for the Facility for ILW Packaging Without Treatment at the Fuel Reprocessing Plant

<u>Job Description</u>	<u>Personnel Required, man-yr/yr</u>
Operators	2
Radiation monitors	1
Maintenance craftsmen	0.3

TABLE 4.4.38. Supply Requirements for the Facility for ILW Packaging Without Treatment at the Fuel Reprocessing Plant

<u>Supply</u>	<u>Use</u>	<u>Annual Requirement</u>
55-gal steel drums	Packaging Waste (general trash)	7200
80-gal steel drums	Packaging waste (ventilation filters)	2900
Wooden pallets	Palletizing waste drums	2600

TABLE 4.4.39. Utility Requirements for the Facility for ILW Packaging Without Treatment at the Fuel Reprocessing Plant

<u>Utility</u>	<u>Use Rate</u>	<u>Annual Requirement</u>
Electricity	200 kW	3×10^5 kWh

TABLE 4.4.40. Secondary Radioactive Wastes from the Facility for ILW Packaging Without Treatment at the Fuel Reprocessing Plant

<u>Description</u>	<u>Annual Volume, m³/yr</u>	<u>Radioactivity Factor^(a)</u>
Combustible and compactable waste	11	1×10^{-6}
Noncombustible trash	0.5	1×10^{-8}

a. Fraction of input activity (Table 4.4.35) in secondary wastes.

4.4.3.7 Emissions from the Facility for ILW Packaging Without Treatment at the FRP

Facility emissions are shown in Table 4.4.41. The only emission route for packaging without treatment is through cell ventilation air. This air, after filtration, is routed to the FRP atmospheric protection system. The release factor for gaseous emissions assumes suspension of 10^{-8} of the activity processed through the facility in the cell air; this factor is probably very conservative.

An estimate of the integrated annual release due to minor accidents (section 4.4.3.9) for this facility is included in Table 4.4.41. It was developed by weighing the minor accident releases by their expected frequencies and summing the quantities for all identified minor accidents. In addition, a contingency was included in the integrated release to account for unidentified minor accidents and to compensate for the uncertainty in expected frequency information.

TABLE 4.4.41. Emissions from the Facility for ILW Packaging Without Treatment at the Fuel Reprocessing Plant

<u>Emission</u>	<u>Description</u>	<u>Annual Quantity</u>	<u>Radioactivity Release Factor to Atmosphere(a)</u>
Gaseous	Ventilation air	$1.6 \times 10^7 \text{ m}^3$	1×10^{-15}
	Minor accident integrated annual release		5×10^{-15}
Other	Heat	$2.8 \times 10^2 \text{ MW-hr}$ ($1 \times 10^9 \text{ BTU}$)	

a. Fraction of input activity (Table 4.4.35) released to atmosphere. Includes DF from main plant APS. Released over 365 days/yr.

4.4.3.8 Decommissioning Considerations for the Facility for ILW Packaging Without Treatment at the FRP

No major items of equipment are involved in this facility. Many, but perhaps not all, of the equipment items would last for the life of the plant. No appreciable buildup of activity in any portion of the facility is expected.

4.4.3.9 Postulated Accidents for the Facility for ILW Packaging Without Treatment at the FRP

Postulated minor accidents for ILW packaging without treatment at the FRP are given in Table 4.4.42. For purposes of environmental consequence analysis a release from Accident 4.4.8 has been designated as an umbrella source term (See Section 3.7-Basis for Accident Analysis). Accident 4.4.8 provided the largest release of activity in its release group from accidents in this waste management system. Source term categories are cross-indexed by accident number in Appendix A of Section 3. To effect a release from the bagged HEPA filter in Accident 4.4.8, the outer drum must break and the inner plastic bag must be ruptured. When the filter is exposed, as much as 0.1% of the activity may become suspended in the cell atmosphere because of the very fine particulate nature of this material.

Other accidents for this technology, which were grouped under other umbrella source terms, included Accident 4.4.6. Rupture of a few bags of trash would not be expected to cause any release since the activity is attached to the trash. In Accident 4.4.7, the frequency estimate is equal to that for Accident 4.4.2 (Section 4.4.1.9) multiplied by the ratio of the amounts of waste processed in the two cases since a fire would be expected to occur only by

TABLE 4.4.42. Minor Accidents for ILW Packaging Without Treatment at the Fuel Reprocessing Plant

Accident No. and Description	Sequence of Events	Safety Systems	Release
4.4.6 - Ruptured waste bags spilled to floor; expected frequency 2/yr.	<ol style="list-style-type: none"> 1. Pallet of drums being transferred by fork-lift truck. 2. Drums are dropped, rupturing some of the drums. 3. Some of the waste bags break, spilling contents on floor. 	<ol style="list-style-type: none"> 1. Spray-wash capability allows decontamination of spill. 	None
4.4.7 - Fire in barrel of bagged trash; expected frequency 0.1/yr.	<ol style="list-style-type: none"> 1. One open barrel of bagged trash ignites and burns or spontaneous ignition of a sealed drum occurs. 	<ol style="list-style-type: none"> 1. Only one barrel open at a time, so fire is limited to one barrel. 2. Self-igniting materials are not normally placed in drums. 3. Extensive fire protection system would quickly extinguish a slow burning trash fire in a barrel. 4. Spray-wash would decontaminate area. 	1.4×10^{-6} of radioactivity in the general trash shown in 55-gal drums in Table 4.4.36 released to cell filters.
4.4.8 - Spent HEPA filters spilled to floor, expected frequency 0.04/yr.	<ol style="list-style-type: none"> 1. Pallet of drums being transferred by fork-lift truck. 2. Drums are dropped, rupturing some of the drums. 3. HEPA filter spills to floor, breaking plastic bag that encloses it. 	<ol style="list-style-type: none"> 1. Spray-wash capability allows decontamination of spill. 	3.4×10^7 of the activity on ventilation filters in 80-gal drums shown in Table 4.4.36 released to drumming area filters.

self-ignition. It is not expected that a fire would spread to more than one drum. This is because only a single drum is open at one time. The method of heat transfer between drums would be by radiation and conduction. Radiation from a low temperature smoldering trash fire would be negligible. Conduction can only occur through the small area of contact between the drums. A fire in a sealed drum which ruptured the drum seal would trigger the fire extinguishing systems.

No accidents that could be classified as moderate or severe accidents could be realistically postulated for this technology.

4.4.3.10 Costs for ILW Packaging Without Treatment at the FRP

Estimates have been made, in mid-1976 dollars, of capital, operating, and levelized unit costs. A complete description of the cost estimate bases, assumptions, and definitions is given in Section 3.8.

Capital Costs. The capital cost estimate for the facility for ILW packaging without treatment at the FRP is shown in Table 4.4.43. This estimate covers all capital costs specifically resulting from inclusion of the facility as an integral part of the reference FRP (described in Section 3.2.3). These costs also include the effect of incremental additions to utility supplies, such as electrical substation; compressed air; heat, ventilation and air conditioning (HVAC); and similar auxiliaries. Also considered are incremental additions to cable, piping and other bulk materials incorporated directly into the ILW packaging without treatment facility. However, general FRP costs for such services as laboratories and warehousing are not allocated to the packaging facility.

The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation, with the exception of working capital.

The high capital cost as compared to the capital costs of the ILW incineration facility (Section 4.4.1.10) is largely a result of provision of three months storage capacity for drummed waste. If a separate interim storage facility is provided at the FRP for all ILW, this much storage capacity would not be needed here and the cost for packaging would be reduced.

TABLE 4.4.43. Capital Cost Estimate for the Facility for ILW Packaging Without Treatment at the Fuel Reprocessing Plant

Cost Element	Manhours, 1000s		Costs, 1000s Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		7	1500	100	1600
Buildings and structures		153	1000	1800	2800
Bulk materials			200		200
Site improvements		—	—	—	—
Subtotal of direct site construction costs		160	2700	1900	4600
Indirect site construction costs	40	30	700	900	1600
Total field cost	40	190	3400	2800	6200
Architectural-engineering services					1100
Subtotal					7300
Owner's cost					2200
Total facility cost					9500
Estimate accuracy range					±25%

Operating Costs. The operating cost components for ILW packaging without treatment are shown in Table 4.4.44. Direct labor costs are based on manpower estimates given in Table 4.4.37. Process material and utility costs are derived from requirements shown in Tables 4.4.38 and 4.4.39. Annual maintenance materials costs are estimated at 3% of initial major equipment costs. Overhead and miscellaneous costs are estimated using the standard method described in Section 3.8.

TABLE 4.4.44. Operating Cost Estimate for
ILW Packaging Without Treatment
at the Fuel Reprocessing Plant

<u>Cost Element</u>	<u>Annual Costs, \$1000s</u>
Direct labor	45
Process materials	240
Utilities	5
Maintenance materials	30
Overhead	70
Miscellaneous	30
Total	420 +50% -25%

Levelized Unit Costs. Table 4.4.45 lists the total levelized unit cost, including the levelized capital and operating costs. The cost calculations assume private ownership of the facilities and a 15-year economic life.

TABLE 4.4.45. Levelized Unit Cost Estimate for ILW
Packaging Without Treatment at the
Fuel Reprocessing Plant

<u>Cost Element</u>	<u>Unit Cost, \$/kg HM</u>
Levelized capital charge	1.70
Levelized operating charge	0.20
Levelized total unit cost	1.90 ±35%

4.4.3.11 Construction Requirements for the Facility for ILW Packaging Without Treatment at the FRP

Many factors relating to the site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating this impact.

Project Schedules and Construction Manpower. The schedule for engineering, procurement and construction of the facility for ILW packaging without treatment is included in the overall schedule for the FRP. This schedule is given in Section 3.2.3. The field labor force estimated for the construction of the facility is tabulated below:

	<u>Man-hours, 1000s</u>
Manual field labor	190
Nonmanual field labor	80
Total field labor	230

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials and services provided at the site of the FRP, while offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is as shown below:

	Costs, \$1000s
Onsite	3000
Offsite	6500
Total	9500

Site Requirements. No site requirements beyond those for the FRP are identifiable for the facility for ILW packaging without treatment. Land commitments for the packaging facility are also included with those of the FRP.

Water. Approximately 3400 m^3 (0.9×10^6 gal) of water are required during the construction period.

Construction Materials. Materials committed to facility construction are:

Concrete	2900 m^3	(3800 yd^3)
Steel	450 MT	(500 tons)
Copper	0.9 MT	(1.0 ton)
Zinc	negligible	negligible
Aluminum	negligible	negligible
Lumber	250 m^3	(100 MFBM)

Energy. Energy resources used during construction are:

Propane	26 m^3	(7,000 gal)
Diesel fuel	260 m^3	(70,000 gal)
Gasoline	170 m^3	(45,000 gal)
Electricity		
Peak demand	200 kW	
Total consumption	130,000 kWh	

Transportation Requirements. No separate transportation requirements for the packaging without treatment facility have been identified beyond those for the FRP.

4.4.3.12 Effects of Fuel Cycle Options

The effects of fuel cycle options on packaging of ILW without treatment at the FRP would be the same as for ILW incineration at the FRP (see Section 4.4.1.12).

4.4.4 Compactable and Combustible LLW Packaging Without Treatment at the Fuel Reprocessing Plant

Packaging of low-level waste without treatment is an alternative to the incineration of this waste as discussed in Section 4.4.2. The low-level waste (LLW) portion of the combustible general trash from the FRP has gamma readings of $<200 \text{ mR/hr}$ in 55-gal steel drums.

The concept of packaging LLW without treatment at the FRP is the same as that presented in Section 4.4.3 for ILW packaging. The only differences between these two operations are those attributable to the lower gamma activity level of the LLW, and to the absence of ventilation filters in the feed to the LLW facility. These differences result in simplification of facility design.

4.4.4.1 Alternatives for LLW Packaging Without Treatment at the FRP

Alternatives for packaging LLW without treatment at the FRP are the same as the alternatives for packaging of ILW without treatment at the FRP (see Section 4.4.3.1).

4.4.4.2 Design Basis of the Facility for LLW Packaging Without Treatment at the FRP

The following assumptions were made in design of the facility for LLW packaging without treatment at the FRP:

- The facility is associated with the operation of the reference 2000-MTHM fuel reprocessing plant. All supporting facilities and services are provided by the reprocessing plant.
- The packaging facility receives 2400 m³ of TRU-contaminated, combustible trash per year. These 2400 m³ include that portion of the combustible general trash from the FRP that has a surface dose rate reading of <200 mR/hr in 55-gal steel drums. Tables 4.4.20 and 4.4.21 define the source, composition, amounts, and activity level of the waste to be received at this facility.
- The facility is designed to package and ship approximately 3800 m³ (135,000 ft³) per year of waste with low gamma activity levels.
- The waste is packaged in 55-gal DOT-17C drums.
- An assay system provides for inventory control of fissile materials.
- Pre-shipment storage capacity is provided for three months of output to compensate for fluctuations in waste generation rate, shipping schedules, and similar factors. Storage space for untreated waste is also provided.
- The design provides a minimum of three levels of confinement, and includes an internal truck bay to meet the confinement requirements for shipping operations.

4.4.4.3 LLW Packaging Without Treatment Process at the FRP

Low-level waste may be received at the facility for LLW packaging without treatment either in plastic-lined, 55-gal drums or in sealed plastic bags in a reusable waste canister. The 55-gal drums are checked for external contamination, for mechanical damage, and integrity of the drum closure. If necessary, the drums are decontaminated and resealed. The waste, in sealed plastic bags, is transferred to a new drum from any unsound drums.

Waste received in sealed plastic bags in the reusable canisters is hand-placed in 55-gal steel drums, and lids are affixed to the drums. All the drums are assayed for fissile material content, checked for external contamination, decontaminated if necessary, and palletized (four drums per pallet). The drums are then removed either to the truck bay for shipment or to the shielded storage area. Drums and pallets of drums are moved by shielded fork-lift.

The input to the facility for LLW packaging without treatment is identical to that to the LLW incineration facility described in Section 4.4.2; the radionuclide content of the LLW is given in Table 4.4.21. The output of the facility for LLW packaging without treatment is given in Table 4.4.46. The drummed waste is sent from this facility to either a final repository or to interim storage.

TABLE 4.4.46. Packaged Wastes from the Facility for LLW Packaging Without Treatment at the Fuel Reprocessing Plant

Volume ^(a)	2,500 m ³ /yr
Density	120 kg/m ³
Ratio of treated volume to untreated volume ^(a)	1.05
55-gal drums/yr	12,000
Container surface dose rate	<0.2 R/hr
Radioactivity as fraction of input ^(b)	1.0

a. Treated volume based on container volume.

b. Fraction of input to the facility (Table 4.4.21)

4.4.4.4 Description of the Facility for LLW Packaging Without Treatment at the FRP

The facility for LLW packaging without treatment at the reference FRP is located in the same area as the ILW incineration facility (see Figure 4.4.6). The facility covers approximately 855 m² (9200 ft²) and houses a drum loading and capping area, the shielded, untreated waste storage bins, an internal truck bay, and a 4600-m³ (139,000 ft³) shielded area for storing about 4750 filled drums stacked four drums high. The building and equipment arrangement is shown in Figure 4.4.26. The facility arrangement provides fire protection and contamination control. The facility service requirements, such as for light, power, heat, and ventilation, are integrated with the FRP services.

The packaging facility is constructed of reinforced concrete to withstand design-basis natural phenomena, including earthquakes and tornadoes, and to prevent penetration by a maximum credible fire and/or explosion. The facility is designed to meet Category I structural requirements.

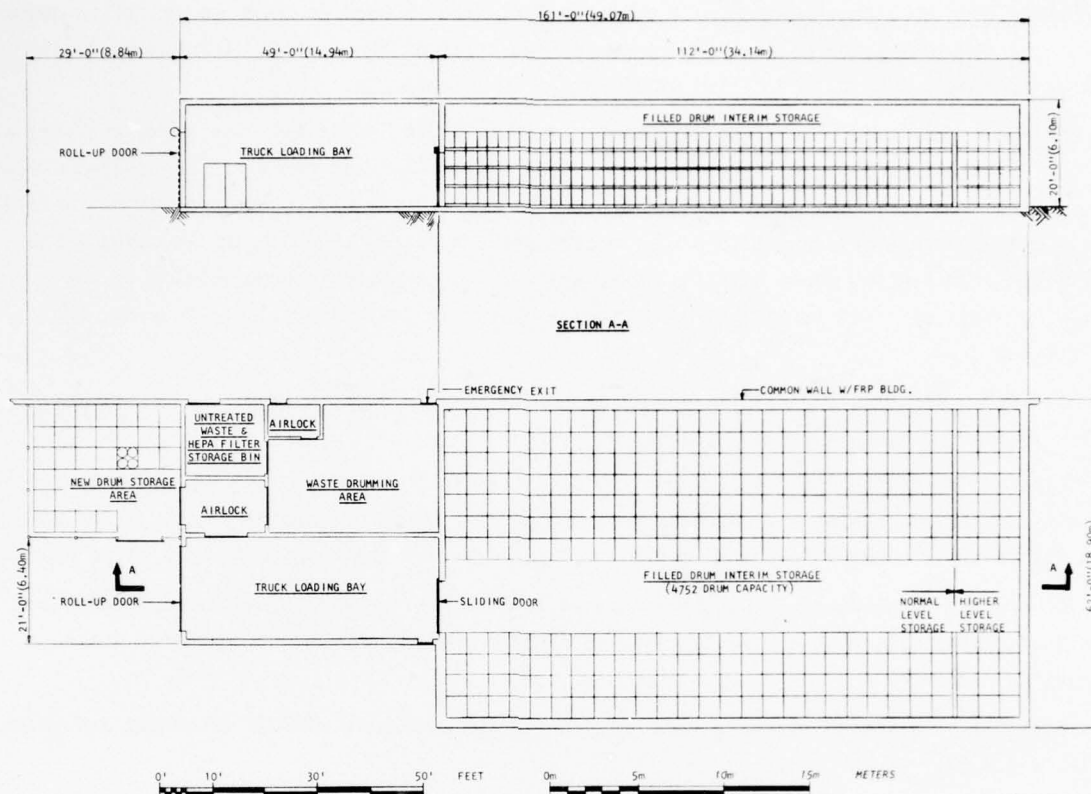


FIGURE 4.4.26. Facility for LLW Packaging Without Treatment Facility at the Fuel Reprocessing Plant, General Plan and Section A-A

Facility Decontamination. A conventional, remotely-operated, water-type sprinkler system is installed so that a decontaminating solution can be sprayed into the drum loading room of the facility to remove surface contamination in the event of an abnormal occurrence. The waste solution is drained to a floor sump, from which it is pumped to the liquid waste system of the FRP.

Fire Protection System. The facility is protected by a wet pipe sprinkler system, except for the drum loading station, which is equipped with a chemical fire suppressant system. The system provides a total flooding of 10 seconds discharge with a minimum of 5% concentration and a 3-minute soak time.

Radiation Monitoring System. Beta-gamma, alpha, and neutron radiation area monitors are strategically located throughout the facility to monitor the radiation levels in all of the operating areas. Representative air samples are monitored continuously to check for any contamination in the operating and storage areas.

Waste Drum Handling Equipment. A shielded fork-lift is used to move new or filled drums within the processing, operating, and surge storage areas of the facility for LLW packaging without treatment and to load filled drums onto truck transports.

Shielding and Remote Handling Equipment. Because of the relatively low gamma activity of the LLW, minimal shielding is required. Individual waste bags and drums can be handled directly but, wherever practical, some shielding is provided for routine continuous operation. Shielding is used on fork-lift trucks to minimize personnel exposure, and both the incoming waste and filled drum storage areas have shielding walls. Simple moveable drum shields or low shielding walls are used to minimize personnel exposure in the drum filling, capping, and palletizing area.

4.4.4.5 Operating and Maintenance Requirements for the Facility for LLW Packaging Without Treatment at the FRP

Like the corresponding facility for ILW discussed in Section 4.4.3.5, the operation of the facility for LLW packaging without treatment can be continuous or intermittent. It can be a single- or multiple-shift operation as long as it is compatible with the amount of waste to be processed.

No special maintenance requirements are expected since fork-lifts, assay equipment, and hand tools constitute most of the facility equipment. All maintenance is expected to be contact maintenance.

Staffing. Estimated staffing requirements for LLW packaging without treatment are shown in Table 4.4.47.

TABLE 4.4.47. Staffing Requirements for the Facility for LLW Packaging Without Treatment at the Fuel Reprocessing Plant

<u>Job Description</u>	<u>Personnel Required, man-yr/yr</u>
Operators	2
Radiation monitors	1
Maintenance craftsmen	0.2

Supplies and Utilities. Table 4.4.48 shows the supplies used in LLW packaging without treatment at the FRP. Table 4.4.49 lists utility requirements for the facility.

TABLE 4.4.48. Supply Requirements for the Facility for LLW Packaging Without Treatment at the Fuel Reprocessing Plant

<u>Supply</u>	<u>Use</u>	<u>Annual Requirement</u>
55-gal steel drums	Packaging waste	12,000
Wooden pallets	Palletizing waste drums	3,000

TABLE 4.4.49. Utility Requirements for the Facility for LLW Packaging Without Treatment at the Fuel Reprocessing Plant

<u>Utility</u>	<u>Use Rate</u>	<u>Annual Requirement</u>
Electricity	40 kW	1×10^5 kWh

4.4.4.6 Secondary Radioactive Wastes from the Facility for LLW Packaging Without Treatment at the FRP

Secondary wastes produced by packaging LLW without treatment are shown in Table 4.4.50. The compactable trash secondary waste shown in Table 4.4.50 is included in the secondary waste accumulated from all the FRP waste treatment facilities (Table 4.4.1) and as such would be fed to an ILW treatment facility (Section 4.4.1 or 4.4.3). In practice this material would be packaged as produced in the LLW facility.

TABLE 4.4.50. Secondary Radioactive Wastes from the Facility for LLW Packaging Without Treatment at the Fuel Reprocessing Plant

<u>Description</u>	<u>Annual Volume, m³/yr</u>	<u>Radioactivity Factor^(a)</u>
Combustible and compactable waste	20	1×10^{-6}

a. Fraction of input activity (Table 4.4.21) in secondary waste.

4.4.4.7 Emissions from the Facility for LLW Packaging Without Treatment at the FRP

Facility emissions are shown in Table 4.4.51. Emission routes for the LLW packaging without treatment facility are the same as those for the ILW facility discussed in Section 4.4.3.7, and facility release factors are based on the same assumptions.

TABLE 4.4.51. Emissions from the Facility for LLW Packaging Without Treatment at the Fuel Reprocessing Plant

<u>Emission</u>	<u>Description</u>	<u>Annual Quantity</u>	<u>Radioactivity Release Factor to Atmosphere^(a)</u>
Gaseous	Ventilation air	1.6×10^7 m ³	1×10^{-15}
	Minor accident integrated annual release		3×10^{-14}
Other	Heat (released to ventilation air)	8.3×10^1 MW-hr (3×10^8 BTU)	

a. Fraction of input activity (Table 4.4.21) released to atmosphere. Includes DF from main plant APS. Released over 365 days/yr.

4.4.4.8 Decommissioning Considerations for the Facility for LLW Packaging Without Treatment at the FRP

No appreciable contamination or activity build-up is expected in the facility for ILW packaging without treatment; total decontamination prior to decommissioning should be relatively simple.

4.4.4.9 Postulated Accidents for the Facility for LLW Packaging Without Treatment at the FRP

Postulated minor accidents for LLW packaging without treatment are given in Table 4.4.52. The basis for estimating release and frequencies of occurrence is the same as discussed in Section 4.4.3.9 for the ILW facility. No accidents that could be classified as moderate or severe accidents could be realistically postulated for this technology.

TABLE 4.4.52. Minor Accidents for the Facility for LLW Packaging Without Treatment at the Fuel Reprocessing Plant

Accident No. and Description	Sequence of Events	Safety System	Release
4.4.6 - Ruptured waste bags spilled to floor; expected frequency 4/yr.	<ol style="list-style-type: none"> 1. Pallet of drums being transferred by fork-lift truck. 2. Drums are dropped, rupturing some of the drums. 3. Some afterwaste bags break, spilling contents on floor. 	<ol style="list-style-type: none"> 1. Spray-wash capability allows decontamination of spill. 	None
4.4.7 - Fire in barrel of bagged trash; expected frequency 0.2/yr.	<ol style="list-style-type: none"> 1. One open drum of bagged trash ignites and burns or spontaneous ignition of a sealed drum occurs. 	<ol style="list-style-type: none"> 1. Only one drum open at a time, so fire is limited to one drum. 2. Self-igniting materials are not normally placed in drums. 3. Extensive fire protection action would quickly extinguish a slow-burning trash fire in a drum. 4. Spray-wash would decontaminate area. 	8×10^{-7} of radionuclides in the annual throughput shown in Table 4.4.21 released to ventilation filter.

4.4.4.10 Costs for the Facility for LLW Packaging Without Treatment at the FRP

Estimates have been made, in mid-1976 dollars, of capital, operating, and levelized unit costs. A complete description of the cost estimate bases, assumptions, and definitions is given in Section 3.8.

Capital Costs. The capital cost estimate for the facility for LLW packaging without treatment at the FRP is shown in Table 4.4.53. This estimate covers all capital costs specifically resulting from inclusion of the facility as an integral part of the FRP (described in Section 3.2.3). These costs also include the effect of incremental additions to

TABLE 4.4.53. Capital Cost Estimate for the Facility for LLW Packaging Without Treatment at the Fuel Reprocessing Plant

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment			200		200
Buildings and structures		110	800	1300	2100
Bulk materials		10	300	100	400
Site improvements		—	—	—	—
Direct site construction costs		120	1300	1400	2700
Indirect site construction costs	30	20	500	700	1200
Total field cost	30	140	1800	2100	3900
Architect-engineer services					700
Subtotal					4600
Owner's cost					1400
Total facility cost					6000
Estimated accuracy range					±25%

utility supplies, such as electrical substations; compressed air; heat, ventilation, and air conditioning (HVAC); and similar auxiliaries; as well as the cable, piping and other bulk materials incorporated directly into the facility for LLW packaging without treatment. However, general FRP costs for such services as laboratories and warehousing are not allocated to the facility.

The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation, with the exception of working capital.

The relatively high capital cost as compared to the capital cost of the LLW incineration facility (Section 4.4.2.10) is largely a result of provision of three months storage capacity for drummed waste. If a separate interim storage facility is provided at the FRP for all ILW, this much storage capacity would not be needed here and the cost for packaging would be reduced.

Operating Costs. The operating cost components for the LLW packaging without treatment facility are shown in Table 4.4.54. Direct labor costs are based on manpower estimates given in Table 4.4.47. Process material and utility costs are derived from requirements shown in

Tables 4.4.48 and 4.4.49. Annual maintenance materials costs are estimated at 3% of initial major equipment costs. Overhead and miscellaneous costs are estimated using the standard method described in Section 3.8.

TABLE 4.4.54. Operating Cost Estimate for the Facility for LLW Packaging Without Treatment at the Fuel Reprocessing Plant

<u>Cost Element</u>	<u>Annual Costs, \$1000s</u>
Direct Labor	45
Process materials	240
Utilities	5
Maintenance materials	5
Overhead	50
Miscellaneous	<u>15</u>
Total	360 $\pm 25\%$

Levelized Unit Costs. Table 4.4.55 lists the total levelized unit cost, including the levelized capital and operating costs. The cost calculation assumes private ownership of the facilities and a 15-year economic life.

TABLE 4.4.55. Levelized Unit Cost Estimate for the Facility for LLW Packaging Without Treatment at the Fuel Reprocessing Plant

<u>Cost Element</u>	<u>Unit Cost, \$/kg HM</u>
Levelized capital charge	.75
Levelized operating charge	<u>.15</u>
Levelized total unit cost	.90 $\pm 30\%$

4.4.4.11 Construction Requirements for the Facility for LLW Packaging Without Treatment at the FRP

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating this impact.

Project Schedules and Construction Manpower. The schedule for engineering, procurement, and construction of the facility for LLW packaging without treatment is an integral factor in the overall schedule for the FRP given in Section 3.2.3. The field labor force estimated for the construction of the LLW packaging without treatment facility is tabulated below:

4.4.83

	Man-hours, 1000s
Manual field labor	140
Nonmanual field labor	<u>30</u>
Total field labor	170

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials and services provided at the site of the FRP, while offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is as shown below:

	Costs, \$1000s
Onsite	2200
Offsite	<u>3800</u>
Total	6000

Site Requirements. No additional site requirements beyond those for the FRP are identifiable for the reference facility. Land commitments for LLW packaging without treatment are included with those of the FRP.

Water. Approximately 2300 m^3 (0.6×10^6 gal) of water are required during the construction period.

Construction Materials. Materials committed to facility construction are:

Concrete	1700 m^3	(2200 yd ³)
Steel	270 MT	(300 tons)
Copper	2.7 m^3	(3 tons)
Lumber	120 m^3	(50 MFBM)

Energy. Energy resources used during construction are:

Propane	19 m^3	(5,000 gal)
Diesel fuel	190 m^3	(50,000 gal)
Gasoline	130 m^3	(35,000 gal)
Electricity		
Peak demand	150 kW	
Total consumption	100,000 kWh	

Transportation Requirements. No separate transportation requirements for the LLW packaging without treatment facility have been identified beyond those for the FRP.

4.4.4.12 Effects of Fuel Cycle Options on LLW Packaging Without Treatment at the FRP

The effects of fuel cycle options on packaging of LLW without treatment at the FRP would be the same as for LLW incineration at the FRP (see Section 4.4.2.12).

4.4.5 Other Alternatives for Compactable and Combustible Wastes Treatment at the Fuel Reprocessing Plant

Sections 4.4.1 through 4.4.4 have presented two alternatives for treating intermediate and low-level compactable and combustible wastes at the FRP, incineration and packaging without treatment. Three other alternatives were mentioned in the introduction to Section 4.4: compaction and packaging; sorting and shredding followed by immobilization in cement or another solid matrix; and acid digestion. Of these, only compaction and packaging has had wide-scale use in the nuclear industry for treating large volumes of such wastes but it has not been applied to ILW wastes.

Compaction reduces the waste volume with some improvements in stability of the waste to fire. Also, transportation, storage, and repository costs are considerably less for the decreased volume of waste than for waste that is packaged without treatment. The small increases in the cost and facility complexity to cover the simple compaction process is expected to be more than offset by the decreased output volume of drummed waste.

Several compaction methods are available.^(2,18) Standard compactors, used most in the nuclear industry, compress the waste material directly into the shipping container (55-gal drum). Volume reduction factors of about five to six are achieved. Balers, another kind of compactor, compress the waste into bales, which are tied, banded, or wrapped to prevent expansion. Volume reduction ratios between 4 and 10 are typical. Bales are then placed into the shipping containers. A third type, baggers, compress the material into slugs that are injected into bags; the bagged waste is later placed in shipping containers. A volume reduction factor of about four results. Packers compress the waste into large storage or shipping containers. On arrival at the disposal site, however, the waste is discharged from the container, allowing re-expansion.

Sorting and shredding of wastes followed by immobilization in a solid matrix, such as cement, has the advantage of increasing the stability of the waste, particularly in that it renders the waste noncombustible. It does not, however, appreciably if at all decrease the waste volume and it greatly increases the weight of the waste. The method is quite useful for small volumes of specialized wastes, such as ion exchange resins, where the increased waste stability is important. This is particularly true for ion exchange resins which have been in contact with nitric acid (as is commonly the case at the FRP) or other oxidants. These resins are potential fire or explosion hazards; immobilization with cement neutralizes any nitric acid remaining and confines the residual water associated with the resins. Such a process is generally considered uneconomical, however, for large volumes of general trash. The cement immobilization process as applied to resins and FRP liquid wastes is treated in detail in Section 4.7.2. It is also the reference treatment alternative for the ash resulting from incineration.

Acid digestion^(2,10) is a low-temperature (230°C - 250°C) oxidation of the organic material in the trash in concentrated sulfuric acid. The oxidant most studied is HNO_3 . The process renders the waste noncombustible. It also has the advantage of rendering actinides in the waste,

such as plutonium, rather easily recoverable. The process is still in the developmental stage and is being demonstrated only on a small scale. Because of the complexity of the equipment involved it cannot be ascertained at this time whether the process would be attractive on the scale needed for treatment of combustible wastes at the FRP.

4.4.6 Incineration of Combustible Waste at a Mixed Oxide Fuel Fabrication Plant

The feed to the incineration process at the mixed oxide fuel fabrication plant (MOX FFP) consists of all the ventilation filters and combustible general trash produced by the main plant and all its associated operations, including waste treatment. The MOX FFP incineration process and equipment are virtually identical to the two controlled-air incineration processes at the fuel reprocessing plant (Sections 4.4.1 and 4.4.2). The equipment and layout are identical to the LLW incineration facility at the FRP (Section 4.4.2), except that a separate filter compactor system is present in the MOX FFP incineration facility to compact and package metal-framed ventilation filters. Also, because its small volume does not appear to warrant a special concentrator, the off-gas scrubbing solution at the MOX FFP is not concentrated.

The reasons for selecting incineration as an alternative for treating this waste are the same as those discussed for the ILW incineration facility at the FRP in the introduction to Section 4.4.1. Incineration of alpha active radioactive waste has been practiced for over 20 years by nations involved with nuclear technology. A list of incineration units and discussions of installation experiences are available from several sources. (5,6,7)

The selected reference treatment system for combustible waste at the MOX FFP is based on controlled-air incineration^(2,3,4) with a high-energy aqueous off-gas scrubbing system. This particular type of incinerator has not been used for incineration of radioactive wastes. The facility discussed here, designed in many respects like the LLW incineration facility at the FRP, may be somewhat oversized for the output of the 400 MTHM per year MOX FFP. Although it may be more practical for one incineration facility to serve more than one site, for the discussions here, only waste from one 400 MTHM per year MOX FFP is processed. If the MOX-FFP is close-coupled with the FRP, the MOX FFP waste could be incinerated in the FRP facility.

4.4.6.1 Alternatives for Incineration at the Mixed Oxide Fuel Fabrication Plant

Alternatives to controlled-air incineration for the ILW waste at the FRP are discussed in Section 4.4.1 and apply equally to the selected reference process discussed here.

4.4.6.2 Design Basis for the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

The following assumptions were made in design of the MOX FFP incineration facility:

- The facility is associated with the operation of the reference 400-MTHM mixed oxide fuel fabrication plant. All supporting facilities and services are provided by the fuel fabrication plant.
- The facility receives 212 m^3 of combustible trash and 40 m^3 of used ventilation filters per year. The source, composition, properties, amount, and activity level of this TRU waste are shown in Tables 4.4.56 and 4.4.57.

TABLE 4.4.56. Wastes Processed in the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

Source	Composition, wt%		Density, kg/m ³	Volume, m ³ /yr
HEPA filters	Metal	60	40	
	Glass	40		
Main plant combustible trash	PVC	33	120	200
	Cellulosics	30		
	Polyethylene	18		
	Latex	9		
	Neoprene	9		
	Styrene	1		
Secondary combustible trash ^(b)	PVC	33	120	12
	Cellulosics	30		
	Polyethylene	18		
	Latex	11		
	Neoprene	9		
	Styrene	1		

a. From primary waste characterization Table 3.3.38 and secondary waste characterization Table 3.5.2.

b. Waste generated by all the waste treatment facilities with the MOX FFP.

TABLE 4.4.57. Radionuclide Content of Waste Treated at the Mixed Oxide Fuel Fabrication Plant Incineration Facility^(a)

	Primary		Secondary	Total
	Combustible Trash	Ventilation Filters	Combustible Trash	
Actinide content, Ci/yr				
²³⁹ Pu	1.6×10^2	3.6×10^2	6.0×10^{-4}	5.2×10^2
²⁴¹ Pu	6.9×10^4	1.6×10^5	2.8×10^{-1}	2.3×10^5
Other Pu	2.6×10^3	6.0×10^3	1.0×10^{-2}	8.6×10^3
²⁴¹ Am	1.1×10^2	2.7×10^2	7.6×10^{-2}	3.8×10^2
Other actinides and daughters	2.4×10^0	5.6×10^0	9.6×10^{-6}	8.4

a. Based on primary waste characterization Table 3.3.38 and secondary waste characterization Table 3.5.2, assuming 400 MTHM/yr fabricated 1 year after plutonium purification.

- The incinerator facility is designed to process the TRU waste discussed above in 560 hours operation per year.
- The MOX FFP incineration facility includes, in addition to the incinerator itself, a filter media pelletizing and filter frame compaction system, a feed preparation subsystem, including sorting and shredding capability, a feed assay subsystem, and an off-gas treatment subsystem, including aqueous scrubbing.
- The incinerator and off-gas treatment train are designed to handle feed consisting of 100% of any one of the major combustible general trash components (cellulosics, plastic, rubber, etc.).
- The assay subsystem provides inventory control for fissile materials in the incineration process and prevents cross-contamination by other classes of waste.
- All utilities required for an orderly process shutdown, such as cooling water, power, ventilation, and compressed gas for pneumatic process controls, are assured by back-up systems.
- The MOX FFP incineration facility is designed to withstand design-basis natural phenomena, including earthquakes and tornadoes, and to prevent penetration by maximum credible fire and/or explosion.

4.4.6.3 Incineration Process at the Mixed Oxide Fuel Fabrication Plant

Table 4.4.57 shows the radionuclide content of the combustible trash and ventilation filters treated at the MOX FFP incineration facility. The incineration process reduces the volume of the trash and converts it to a noncombustible ash from which transuranium elements such as plutonium can be recovered (if it is found desirable or economically feasible to do so). The facility also punches out and pelletizes the filter media from the ventilation filters and compacts the metal filter frames. The pelletized media and compacted frames are packed in 55-gal drums for shipment either to interim storage or the repository.

The layout, equipment, and operation of the MOX FFP feed preparation, assay, controlled-air incinerator charging, incineration, ash collection, off-gas treatment, scrubbing solution recycle, and auxiliary utilities subsystems are identical to those of the LLW incineration facility discussed in Section 4.4.2, and are very similar to those of the ILW incineration facility discussed in Section 4.4.1. The process differences between the LLW incineration facility at the FRP and the MOX FFP facility are the lower annual feed volumes, different feed radionuclide content, the processing of ventilation filters, and the lack of scrubbing solution concentration at the latter. The overall MOX FFP incineration system flowsheet is shown in Figure 4.4.27.

Feed Preparation. The function and operation of the MOX FFP feed preparation subsystem is the same as that discussed for the ILW incineration facility at an FRP in Section 4.4.1.3, except that the MOX FFP system does not involve wooden filter frames. Also, the MOX FFP uses a glove box-contained system with direct rather than remote operation, as discussed in Section 4.4.2.3. Figure 4.4.28 is a flow diagram of the feed preparation subsystem; Table 4.4.58 gives stream data.

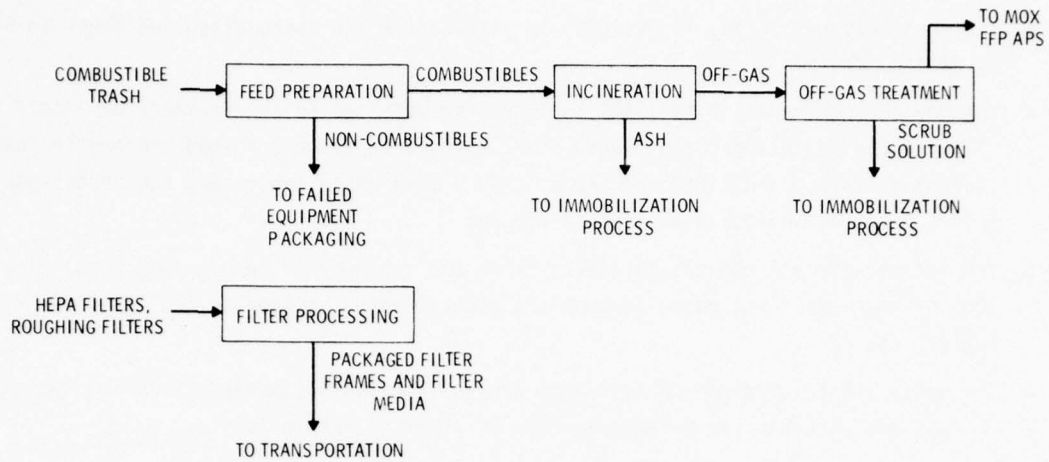


FIGURE 4.4.27. Process Flowsheet for the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

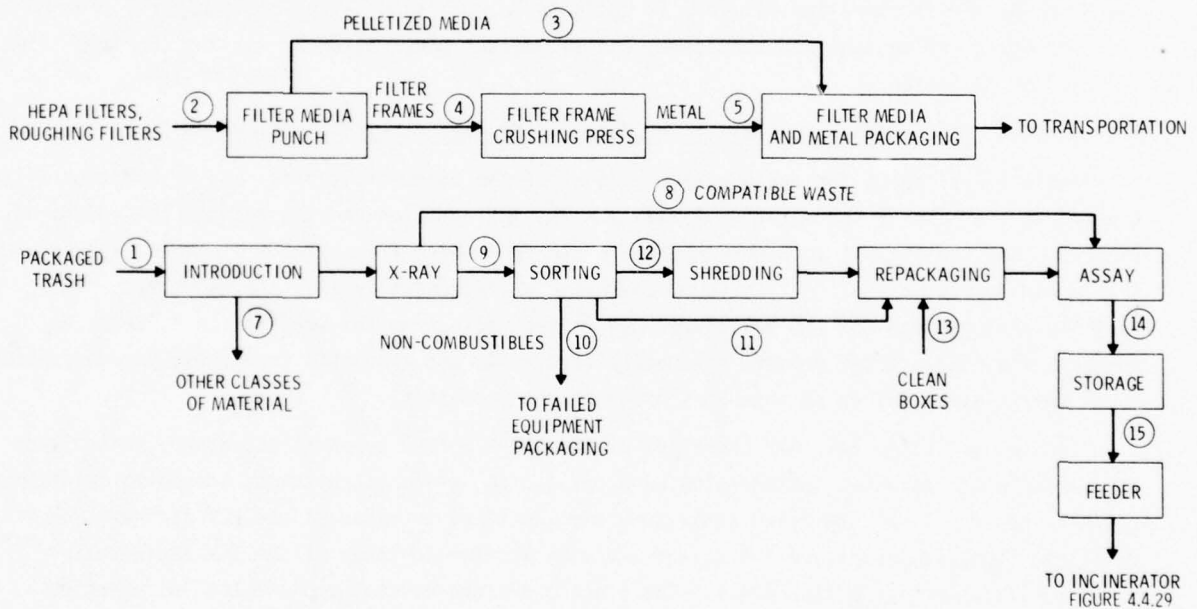


FIGURE 4.4.28. Feed Preparation Flow Diagram for the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant (Circled numbers refer to stream numbers in Table 4.4.58.)

TABLE 4.4.58. Feed Preparation Stream Flow Data for the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

Stream Number	Description	Rate ^(a)	Radioactivity Fraction ^(b)
1	Packaged waste, general trash	25,000 kg/yr	0.3
2	Ventilation filters	6,400 kg/yr	0.7
3	Pelletized filter media	2,560 kg/yr	0.7
4	Filter frames	3,840 kg/yr	0.014
5	Filter frame metal	3,840 kg/yr	0.014
6	Drummed filter material	6,400 kg/yr (50 drums)	0.7
7	Other classes of material (included for completeness)	0	0
8	Compatible waste (75% of general trash)	19,000 kg/yr	0.23
9	Waste requiring sorting (25% of general trash)	6,000 kg/yr	0.075
10	Noncombustible for packaging with failed equipment included for completeness)	0	0
11	Sorted combustible waste not requiring shredding	3,000 kg/yr	0.037
12	Combustible waste requiring shredding	3,000 kg/yr	0.038
13	New boxes for repackaging waste	460	0
14	Waste to storage	25,000 kg/yr	0.3
15	Waste to incinerator	45 kg/hr (25,000 kg/yr)	0.3

a. Rates in units of hours are instantaneous rates based on 560 hr of incinerator operation per year.

b. Fraction of total input (Table 4.4.57) in the indicated stream.

Assay. The assay subsystem has the same function in the MOX FFP incineration facility as the assay subsystem for the ILW incineration facility at the FRP (see Section 4.4.1.3). The assay systems which have been used for wastes contaminated with weapons-grade plutonium can likely be modified to assay wastes contaminated with plutonium that has been recycled from a light water reactor (LWR). Assay of the ash within the hopper and of the scrub solution stream require development. As an alternative, the ash and scrub solution could be sampled and chemically analyzed.

Incineration Charging. The function and operation of the MOX FFP ram feeder is the same as that of the LLW incineration facility discussed in Section 4.4.2.3.

Incineration and Ash Collection. Incinerator operation is identical to that described for the ILW incinerator at the FRP except that no liquids are fed to the MOX FFP incinerator. The operation of the ash collection subsystem is the same as that of the ILW incineration facility at the FRP (Section 4.4.1.3) except that the ash is vacuumed by hand through a glove

box-enclosed door to the lower chamber instead of by manipulators in a shielded cell. The incineration and ash collection flow diagram and stream data are given in Figure 4.4.29 and Table 4.4.59, respectively.

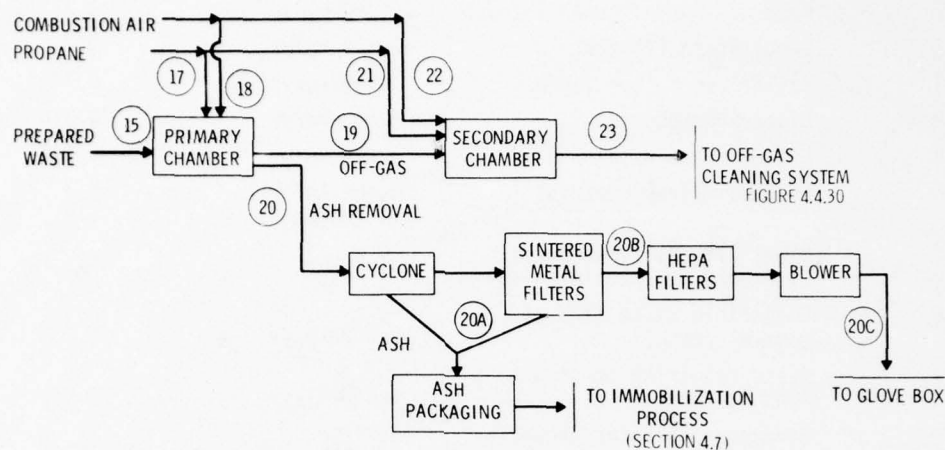


FIGURE 4.4.29. Incineration and Ash Collection Flow Diagram for the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant
(Circled numbers refer to stream numbers in Table 4.4.61.)

TABLE 4.4.59. Incineration and Ash Collection Stream Flow Data for the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

Stream Number	Description	Rate ^(b)	Radioactivity Fraction ^(a)
15	Solid waste to incinerator	45 kg/hr	0.3
17	Primary chamber propane supply	0-0.5 m ³ /min (STP)	0
18	Primary chamber air supply	3-10 m ³ /min (STP)	0
19	Primary chamber off-gas	4-10 m ³ /min (STP)	0.0012
20	Ash removal system (not operative during processing):		
20A	ash	2,000 kg/yr (8.3 m ³ /yr)	0.3
20B	transport air	8.5 m ³ /min	
20C	filtered air	8.5 m ³ /min	3 x 10 ⁻¹³
21	Secondary chamber propane supply	0-0.5 m ³ /min (STP)	0
22	Secondary chamber air supply	1.4-10 m ³ /min (STP)	0
23	Incinerator off-gas	7-20 m ³ /min (STP)	0.0012

a. Fraction of total input (Table 4.4.57) in the indicated stream.

b. Rates in units of hours or minutes are instantaneous rates based on 560 hrs of incinerator operation per year.

Off-gas Treatment. Off-gas treatment for the MOX FFP incineration facility is identical to that presented in Section 4.4.1.3, with the final cleaned off-gas routed to the MOX FFP atmospheric protection system. The flow diagram and stream data for the MOX FFP incinerator off-gas treatment system are given in Figure 4.4.30 and Table 4.4.60. The scrubbing solution is routed directly without concentration to the MOX FFP wet waste and particulate solids immobilization facility (see Section 4.7).

Scrubbing Solution Recycle. Scrubbing solution recycle operation is the same as that described in Section 4.4.1.3. The flowsheet and stream data for this subsystem are included in Figure 4.4.30 and Table 4.4.60.

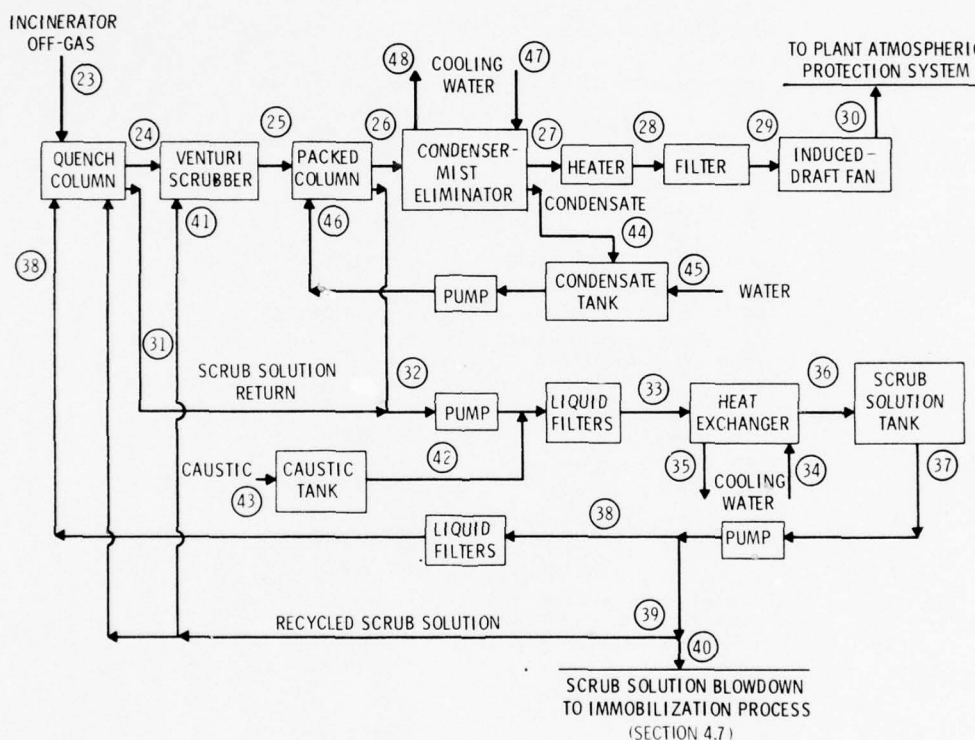


FIGURE 4.4.30. Off-Gas Treatment Flow Diagram for the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

Filter Processing. Filter processing can be considered a separate and more or less unrelated part of the MOX FFP incineration facility; no part of the filter is incinerated. Filter media are pressed from the frames and pelletized, the frames are crushed, and the pelletized media and crushed frames are packaged in 55-gal drums in exactly the same manner as discussed in more detail under ILW feed preparation in Section 4.4.1.3. The only difference is that the operation is carried out in a glovebox instead of a hot-cell. The flowsheet and stream data for this process are included in Figure 4.4.28 and Table 4.4.58.

TABLE 4.4.60. Off-gas Treatment Stream Flow Data for the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

Stream Number	Description	Rate ^(b)	Radioactivity Fraction ^(b)
23	Incinerator off-gas (1100°C)	7-20 m ³ /min (STP)	1.2 x 10 ⁻³
24	Quenched off-gas (77°C)	14-40 m ³ /min (STP)	1.2 x 10 ⁻³
25	Venturi scrubber off-gas (particles removed)	14-40 m ³ /min (STP)	2.4 x 10 ⁻⁵
26	Packed column off-gas (mineral acids removed) (65°C)	14-40 m ³ /min (STP)	2.4 x 10 ⁻⁵
27	Condenser off-gas (50°C) (most of water removed)	7.6 -21 m ³ /min (STP)	2.4 x 10 ⁻⁵
28	Superheated off-gas (60°C)	7.6 -21 m ³ /min (STP)	2.4 x 10 ⁻⁵
29	Filtered off-gas	7.6-21 m ³ /min (STP)	2.4 x 10 ⁻¹²
30	Cleaned off-gas to plant atmospheric protection system	7.6-21 m ³ /min (STP)	2.4 x 10 ⁻¹²
31	Excess quench liquid return	60-72 l/min	---
32	Venturi scrubber and packed column liquid return	57-87 l/min	1.2 x 10 ⁻³
33	Neutralized scrub solution return after particulate removal	117-159 l/min	3 x 10 ⁻⁴
34	Scrub solution cooler, water supply (24°C)	530 l/min	0
35	Scrub solution cooler, water return (32°C)	530 l/min	0
36	Cooled scrub solution to hold tank (32°C)	117-159 l/min	3 x 10 ⁻⁴
37	Scrub solution tank outlet	117-159 l/min	3 x 10 ⁻⁴
38	Recycled scrub solution to quench column weir (filtered to remove additional particulates)	45 l/min	---
39	Recycled scrub solution to quench column and venturi scrubber	68-98 l/min	---
40	Scrub solution blowdown to immobilization facility (32°C)	3.8 l/min (1.28 x 10 ⁵ l/yr)	3 x 10 ⁻⁴
41	Venturi solution	38-68 l/min	---
42	Caustic solution (20% NaOH) addition	0-1.9 l/min	0
43	Solid caustic and water		0
44	Condensate return	7.6-15 l/min	---
45	Scrubbing solution makeup water	3.8-19 l/min	0
46	Condensate recycle to packed column	19 l/min	---
47	Condenser cooling water supply (t _c)	360 l/min	0
48	Condenser cooling water return (t _c + 20°C)	360 l/min	0

a. Instantaneous rates based on 560 hr of incinerator operation per year.

b. Fraction of total input (Table 4.4.57) in the indicated stream.

Auxiliary Utilities. The purpose and operation of auxiliary utilities in the MOX FFP incineration facility are identical to those described in Section 4.4.1.3.

Incineration Facility Products. The product of waste treatment in the MOX FFP incineration facility is shown in Table 4.4.61. Ash and scrubbing solution are also produced, but they receive further treatment in the wet wastes and particulate solids treatment facility, so are considered to be secondary wastes and are described as such in Section 4.4.6.6.

TABLE 4.4.61. Packaged Waste Leaving the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

Product	Volume, ^(a) m ³ /yr	Density, kg/m ³	Ratio of Treated Volume ^(a) to Untreated Volume	Drums/yr, 55-gal	Radioactivity as Fraction of Input ^(b)
Pelletized filter media and frames ($<0.2R/hr$)	10	640	0.25	50	0.7

a. Treated volume based on container volume.

b. Fraction of total input (Table 4.4.57).

4.4.6.4 Description of the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

The MOX FFP incineration facility is located in the production maintenance and waste area, between the special nuclear materials rework and recovery operation area and the process support area, as a direct attachment to the main pellet and rod production areas of the MOX FFP. Figure 4.4.31 shows the position of this facility in relation to the rest of the facilities in the MOX FFP complex.

The controlled-air incineration system is housed in a concrete structure approximately 32 m by 16 m (105 ft by 53 ft). The floor plan of the facility is shown in Figure 4.4.32. The MOX FFP incineration facility is identical to the LLW incineration facility at the FRP, as discussed in Section 4.4.2.4, except that the MOX FFP facility provides a room where a HEPA filter compactor is enclosed in a glove box, as seen in Figure 4.4.32. The section view of the facility is identical to that shown in Figure 4.4.20 in Section 4.4.2.4.

Equipment. Since the MOX FFP waste incineration facility is identical to the LLW incineration facility (except for the inclusion of filter compaction equipment at the MOX FFP facility), the equipment items are not described again here. The filter compaction equipment, x-ray scanner, feed shredder, assay equipment, ram feeder, controlled-air incinerator, entire off-gas treatment train, and scrubbing solution recycle equipment are discussed in Section 4.4.1.4. The MOX FFP facility does not include scrub solution concentration equipment; instead the scrub solution is sent directly to the immobilization facility (see Section 4.7).

Shielding and Remote Handling Equipment. Shielding requirements for the MOX FFP incineration facility are the same as those discussed in Section 4.4.2.4.

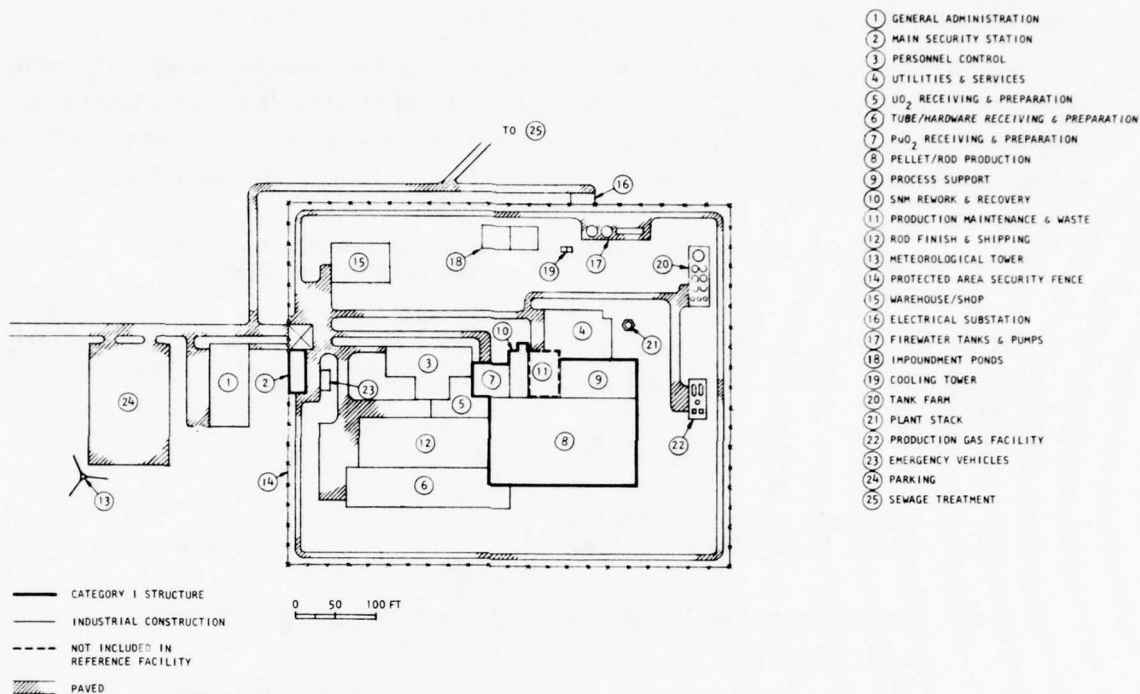


FIGURE 4.4.31. Approximate Location of the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

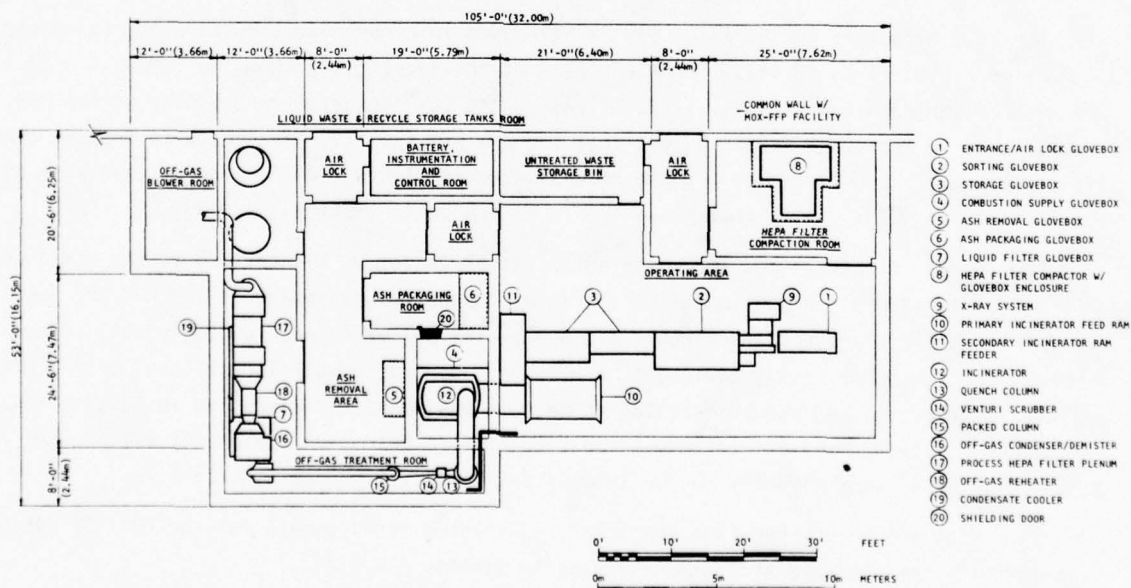


FIGURE 4.4.32. Incineration Facility at the Mixed Oxide Fuel Fabrication Plant, General Plan

4.4.6.5 Operating and Maintenance Requirements for the Mixed Oxide Fuel Fabrication Plant Incineration Facility

Operating and maintenance requirements for the MOX FFP incineration facility are similar to those of the LLW incineration facility at the FRP (Section 4.4.2.5) but are carried out on a smaller scale.

The MOX FFP facility uses lower feed rates and operates many fewer hours per year (560 hours per year). Because of the smaller number of operating hours, the equipment failure rate should be much lower than that of the LLW incineration facility at the FRP. All major equipment items, including the incinerator primary and secondary chambers, are expected to last for the life of the MOX FFP plant.

Staffing. Estimated staffing requirements for the MOX FFP incineration facility are shown in Table 4.4.62. Daily manpower requirements vary in the same manner as discussed in Section 4.4.1.5.

TABLE 4.4.62. Staffing Requirements for the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

<u>Job Description</u>	<u>Personnel Required, man-yr/yr</u>
Operators	2.7
Monitors	1.0
Maintenance craftsmen	0.3

Supplies and Utilities. Table 4.4.63 shows essential materials used in the MOX FFP incineration facility operation. Table 4.4.64 lists utilities required for this operation.

TABLE 4.4.63. Supply Requirements for the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

<u>Material</u>	<u>Use</u>	<u>Annual Requirement</u>
NaOH	pH control in off-gas scrubbing solution	3750 kg
Cardboard boxes	Repackaging of sorted and shredded waste to be incinerated	460
Steel drums (55-gal)	Packaging of pelletized filter media and crushed metal frames	50

4.4.6.6 Mixed Oxide Fuel Fabrication Plant Incineration Facility Secondary Radioactive Wastes

Secondary wastes produced by the MOX FFP incineration facility are shown in Table 4.4.65. The basis for determining the secondary waste volumes and activities shown in Table 4.4.65 are

TABLE 4.4.64. Utility Requirements for the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

Utility	Use Rate	Annual Requirement
Electricity	800 kW	1×10^6 kWh
Propane	$15 \text{ m}^3/\text{hr}$	$7 \times 10^3 \text{ m}^3$ (STP)
Air	$8.7 \times 10^3 \text{ m}^3/\text{hr}$	$4.8 \times 10^5 \text{ m}^3$
Water consumed	$1.4 \times 10^3 \text{ kg/hr}$	$7.8 \times 10^5 \text{ kg}$

TABLE 4.4.65. Secondary Radioactive Wastes from the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

Description	Annual Volume, m^3/yr	Radioactivity Factor ^(a)
Incinerator ash	8.3	0.3
Scrubbing solution	$128 (1.3 \times 10^5 \text{ kg})$	3×10^{-4}
Noncombustible general trash and failed equipment	1	1×10^{-5}
Combustible and compactable waste	2	1×10^{-6}

a. Fraction of input activity (Table 4.4.57) in the secondary waste.

the same as for the ILW incineration facility (see Section 4.4.1.6). The composition of the scrubbing solution is shown in Table 4.4.66. The lower activity level of noncombustible trash and failed equipment from the MOX FFP incineration facility, as compared to the two FRP incineration facilities (Sections 4.4.1.6 and 4.4.2.6), reflect the expectation that the primary and secondary incinerator chambers will not have to be replaced during the life of the plant. Combustible general trash, including scrubbing solution recycle filters, is recycled directly to the incineration facility.

TABLE 4.4.66. Composition of the Scrubbing Solution for the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

Volume	$1.3 \times 10^5 \text{ L/yr}$
Specific gravity	1.02
Chemical composition	
pH	7 to 9
NaCl	0.5 M
NaHCO_3	0.1 M
Na_2SO_3 and Na_2SO_4	0.01 M
Particles	0.2 g/L

4.4.6.7 Emissions from the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

Facility emissions are shown in Table 4.4.67. The activity levels in the gaseous emission are based on the same estimates as those made for the two FRP incineration facilities, as discussed in Sections 4.4.1.7 and 4.4.2.7. The values in Table 4.4.67 are considered conservative for reasons presented in the earlier sections.

TABLE 4.4.67. Emissions from the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

<u>Emission</u>	<u>Description</u>	<u>Annual Quantity</u>		<u>Radioactivity Release Factor to Atmosphere(a)</u>
Gaseous	Cleaned incinerator off-gas	Air	$4.8 \times 10^5 \text{ m}^3$	2×10^{-19}
		HCl	8.5 kg	
		SO _x	15 kg	
		NO _x	33 kg	
		CO	17 kg	
	Minor accident integrated annual release			3×10^{-15}
Cooling tower water	Evaporated (T = 38°C)	6.6×10^5 kg		
	Drift (T = 38°C)	3.2×10^3 kg		
	Blowdown (T = 27°C)	1.2×10^5 kg		
Other	Heat			
	to cooling tower	4.4×10^2 MW-hr (1.5×10^9 BTU)		
	in gaseous emission	6.7×10^1 MW-hr (2.3×10^8 BTU)		

a. Fraction of total input (Table 4.4.57) released to atmosphere. Includes DF of 10^7 from APS. Released over 560 hr/yr.

An estimate of the integrated annual release due to minor accidents (Section 4.4.6.9) for this facility is included in Table 4.4.67. It was developed by weighing the minor accident releases by their expected frequencies and summing the quantities for all identified minor accidents. In addition, a contingency was included in the integrated release to account for unidentified minor accidents and to compensate for the uncertainty in expected frequency information. Estimated integrated annual releases due to minor accidents for this technology are seen in Table 4.4.67 to be much greater than the normal operational release.

4.4.6.8 Decommissioning Considerations for the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

All major equipment items in the incineration facility are expected to last for the life of the MOX FFP. Only slight build-up of actinide activity in the incinerator refractory is

expected (unlike the case of fission products in the FRP incinerators discussed in Section 4.4.1.8 and 4.4.2.8). No appreciable build-up is expected in other equipment in the facility. Overall, the decommissioning of this facility would be similar to decommissioning of typical alpha-active facilities, such as the other major parts of the MOX FFP.

4.4.6.9 Postulated Accidents for the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

Postulated minor and moderate accident scenarios for the MOX FFP incineration facility are shown in Tables 4.4.68 and 4.4.69, respectively. These scenarios are identical to those for the LLW incineration facility at the fuel reprocessing plant (see Section 4.4.2.9) except that the release values differ because of differences in the fraction of annual throughput in the facility at any one time. The release values are determined in the same manner as those for the ILW and LLW incinerators at the FRP (see Sections 4.4.1.9 and 4.4.2.9). No accidents that could be classified as severe accidents could be realistically postulated for this technology.

TABLE 4.4.68. Minor Accidents for the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

Accident No. and Description	Sequence of Events	Safety System	Release
4.4.1-Loss of cooling water to incinerator off-gas treatment system; expected frequency 0.05/yr.	<ol style="list-style-type: none"> 1. Cooling water flow to off-gas treatment system fails. 2. Humidity in off-gas rises. 3. HEPA filters slowly plug due to condensing moisture. 4. HEPA filter blockage shuts down system in about 30 minutes. 	<ol style="list-style-type: none"> 1. Slow blockage of airflow allows adequate time for equipment shutdown to be carried out. 2. A two-hour back-up supply of pressurized water to quench column prevents other effects of coolant loss from occurring. 	None
4.4.2-Minor fire in feed preparation system; expected frequency 0.2/yr.	<ol style="list-style-type: none"> 1. Fire starts in trash in feed preparation area. 2. Small fire is detected and extinguished. 	<ol style="list-style-type: none"> 1. Well-designed automatic fire suppression system. 2. Additional manual operated fire suppression equipment. 	2.2×10^{-4} of radionuclides in combustible trash released to glove box filters. (Table 4.4.57)

4.4.6.10 Costs for the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

Estimates have been made, in mid-1976 dollars, of capital, operating and levelized unit costs. A complete description of the cost estimate bases, assumptions and definitions is given in Section 3.8.

TABLE 4.4.69. Moderate Accidents for the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

Accident No. and Description	Sequence of Events	Safety Systems	Release
4.4.3 - Major fire in feed preparation line; expected frequency 0.01/yr.	<ol style="list-style-type: none"> 1. Feed preparation line contains maximum loading of waste (24 hr of incinerator feed). 2. Fire initiates in waste. 3. Fire suppression system does not operate. 4. Glovebox atmospheric filters fail because of fire. 	<ol style="list-style-type: none"> 1. Well-designed automatic fire suppression system would be used. 2. Additional manual or redundant automatic fire suppression equipment could be used. 	2.2×10^{-2} of radionuclides in combustible trash (Table 4.4.57) released to plant APS.
4.4.4 - Explosion in feed preparation system; expected frequency 0.02/yr.	<ol style="list-style-type: none"> 1. Small amounts of explosive material in waste. 2. Such material explodes during sorting operation. 	<ol style="list-style-type: none"> 1. Explosives or explosive chemicals are not used in MOX FFP operation. 2. Waste form designed to prevent formation of explosive material. 	5×10^{-4} of radionuclides in combustible trash (Table 4.4.57) released to cell filters.
4.4.5 - Incinerator explosion; expected frequency 0.01/yr.	<ol style="list-style-type: none"> 1. Flame-out occurs in incinerator. 2. Explosive reignition of propane-air mixture in incinerator causes breach of incinerator integrity. 3. 50% of ash in incinerator at minimum load is suspended in cell air. 	<ol style="list-style-type: none"> 1. Incinerator control system greatly reduces probability of occurrence. 2. Automatic fire-control sprinkler would activate, lowering amount of airborne particles. 	9×10^{-2} of radionuclides in combustible trash (Table 4.4.57) released to cell filters.

Capital Costs. The capital cost estimate for the MOX FFP incineration facility is shown in Table 4.4.70. This estimate covers all capital costs specifically resulting from inclusion of the facility as an integral part of the MOX FFP described in Section 3.2. These costs also include the effect of incremental additions to utilities, such as electricity; compressed air; and heating, ventilation, and air conditioning (HVAC); as well as the cable, piping and other bulk materials incorporated directly into the waste incineration facility. However, general MOX FFP costs for such services as laboratories and warehousing have not been allocated to the reference facility.

The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation, with the exception of working capital and the cost of waste containers required to hold untreated waste packages (considered part of the operating cost).

TABLE 4.4.70. Capital Cost Estimate for the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		4	850	50	900
Buildings and structures		42	400	500	900
Bulk materials		21	750	250	1000
Site improvements		—	—	—	—
Subtotal of direct site construction costs		67	2000	800	2800
Indirect site construction costs	18	13	300	400	700
Total field cost	18	80	2300	1200	3500
Architect-engineer services					700
Subtotal					4200
Owner's cost					1300
Total facility cost					5500
Estimate accuracy range					±25%

Operating Costs. The operating cost components for the MOX FFP incineration facility are tabulated in Table 4.4.71. Direct labor costs are based on manpower requirements shown in Table 4.4.62. Process material and utility costs are derived from requirements given in Tables 4.4.63 and 4.4.64. Maintenance materials costs are estimated at 3% of initial major equipment costs. Overhead and miscellaneous costs are calculated as described in Section 3.8.

TABLE 4.4.71. Operating Cost Estimate for Incineration at the Mixed Oxide Fuel Fabrication Plant

Cost Element	Annual Costs \$1000s
Direct labor	60
Process materials	5
Utilities	15
Maintenance materials	25
Overhead	80
Miscellaneous	15
Total	200
	+50%
	-25%

Levelized Unit Cost. Table 4.4.72 shows the total levelized unit cost including the levelized capital and operating costs. The cost calculation assumes private ownership of the facilities and a 15-year economic life. Because of the small amount of waste processed

TABLE 4.4.72. Levelized Unit Cost Estimate for Incineration at the Mixed Oxide Fuel Fabrication Plant

Cost Element	Unit Cost, \$/kgHM(a)
Levelized capital charge	3.45
Levelized operating charge	.85
Levelized total unit cost	4.30 \pm 35%

a. Dollars per kgHM MOX fuel. To convert to \$/kgHM reprocessed, divide by five.

this facility is underused. Other alternatives such as a smaller incinerator, compaction and packaging, or incineration at the FRP if the FRP and the MOX-FFP are close-coupled, may be more attractive economically.

4.4.6.11 Construction Requirements for the Incineration Facility at the Mixed Oxide Fuel Fabrication Plant

Construction requirements for the MOX FFP incineration facility are identical to those discussed in Section 4.4.2.11.

4.4.6.12 Effects of Fuel Cycle Options on Waste Incineration at the MOX FFP

The reference process for incineration of waste at the MOX FFP assumes reprocessing of LWR fuel and recycling the recovered uranium and plutonium. The fuel cycle options, 1) no recycle, 2) uranium recycle only with plutonium to a repository, and 3) uranium recycle only with plutonium to the high-level waste, would all eliminate the MOX FFP and the need for an incineration facility to process its combustible waste.

4.4.7 Compactable and Combustible Waste Packaging Without Treatment at a Mixed Oxide Fuel Fabrication Plant

Packaging of compactable and combustible waste without treatment is an alternative to incineration of this waste (see Section 4.4.6). The waste comprises spent ventilation filters and the general combustible trash from the mixed oxide fuel fabrication plant (MOX FFP) and from all the waste treatment facilities associated with it (secondary waste).

The concept and operation of the facility for packaging without treatment at the MOX FFP are identical to that presented in Section 4.4.4 for LLW packaging without treatment at the fuel reprocessing plant. The two facilities differ in size, particularly for preshipment storage, because of the much lower waste volume to be processed at the MOX FFP.

4.4.7.1 Alternatives for Packaging Without Treatment at the Mixed Oxide Fuel Fabrication Plant

Alternatives within the concept of packaging without treatment at the MOX FFP are the same as those discussed in Section 4.4.3.1.

4.4.7.2 Facility Design Basis for Packaging Without Treatment at the Mixed Oxide Fuel Fabrication Plant

The following assumptions were made in design of the facility for packaging without treatment at the MOX FFP:

- The facility is associated with the operation of the reference 400 MTHM mixed oxide fuel fabrication plant. All supporting facilities and services are provided by the fuel fabrication plant.
- The facility receives 212 m³ of combustible trash and 40 m³ of spent ventilation filters per year. The source, composition, properties, amount, and activity level of this waste are shown in Tables 4.4.56 and 4.4.57.
- This facility is designed to package and ship approximately 310 m³ (11,000 ft³) of TRU-contaminated waste per year.
- General trash is packaged in 55-gal DOT-17c drums; HEPA filters are packaged in 80-gal drums.
- An assay system provides for inventory control of fissile materials.
- Preshipment storage capacity is provided for three months of output to compensate for fluctuations in waste generation rate, shipping schedules, and similar factors. Storage space for untreated waste is also provided.
- The design provides a minimum of three levels of confinement and includes an internal truck bay to meet the confinement requirements for shipping operations.

4.4.7.3 Packaging Without Treatment Process at the Mixed Oxide Fuel Fabrication Plant

The operation of the facility for packaging without treatment at the MOX FFP is identical to that described for LLW packaging without treatment at the FRP (see Section 4.4.4.3) except that HEPA filters are not received in the LLW facility. HEPA filters are handled at the MOX FFP facility in the same manner as the compactable and combustible trash except that they are packaged in 80-gal rather than 55-gal drums.

The input for the MOX FFP facility for packaging without treatment is shown in Table 4.4.57; the output is given in Table 4.4.73. The drummed waste is sent from this facility to either a final repository or to interim storage.

4.4.7.4 Facility Description for Packaging Without Treatment at the Mixed Oxide Fuel Fabrication Plant

The facility for packaging without treatment at the MOX FFP is an alternative to the incineration facility and would occupy the same general area assigned to that facility and described

TABLE 4.4.73. Packaged Waste Leaving the Facility for Packaging Without Treatment at the Mixed Oxide Fuel Fabrication Plant

Waste (a)	Volume (b) m ³ /yr	Density, kg/m ³	Ratio of Treated Volume to Untreated Volume (b)	Containers/yr		Radioactivity, as Fraction of Input (c)
				55-gal	80-gal	
Combustible trash	220	120	1.05	1050		0.3
Ventilation filters	108	60	2.7		350	0.7

- a. Container surface dose rate <0.2 R/hr.
 b. Treated volume based on container volume.
 c. Fraction of total input (Table 4.4.57).

in Section 4.4.6.4. The facility covers approximately 217 m² (2340 ft²) and houses a drum loading and capping area, shielded untreated waste storage bins, an internal truck bay, and a 400-m³ (14,100-ft³) shielded area for storage of about 380 filled drums stacked four high. The building and equipment arrangement is shown in Figure 4.4.33. The facility arrangement provides fire protection and contamination control. The facility service requirements, such as for light, power, heat, and ventilation, are integrated with the overall MOX FFP services.

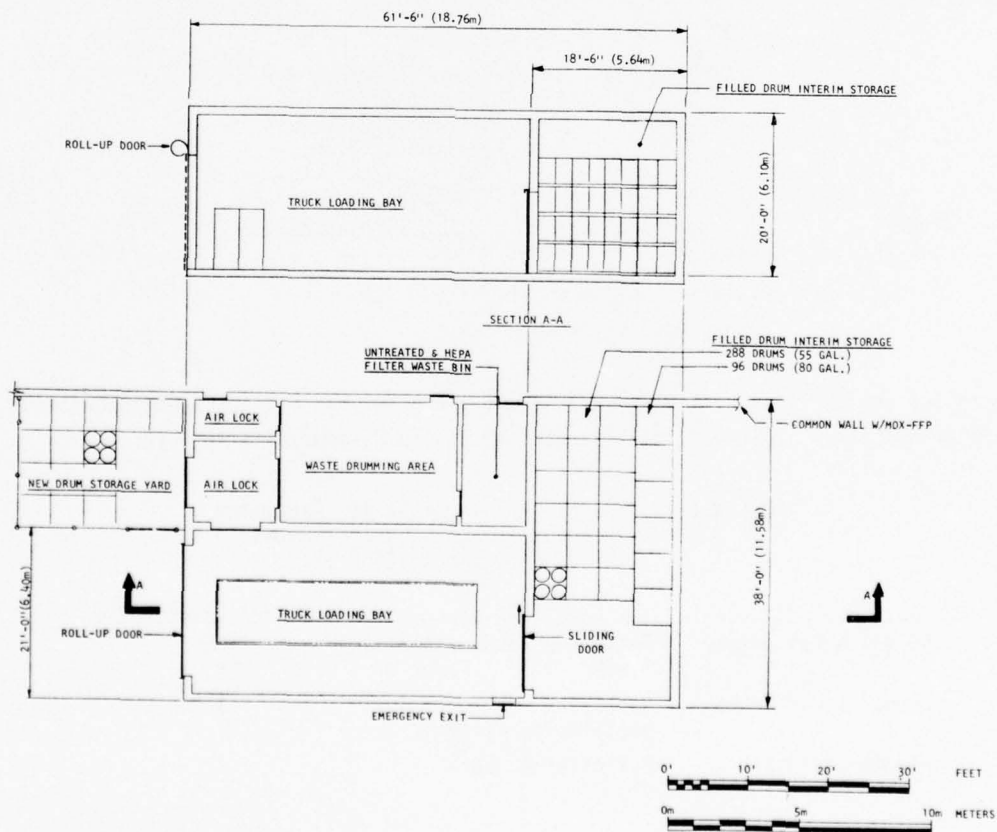


FIGURE 4.4.33. Facility for Packaging Without Treatment at the Mixed Oxide Fuel Fabrication Plant, General Plan

The MOX FFP facility for packaging without treatment is constructed of reinforced concrete to withstand design-basis natural phenomena, including earthquakes and tornadoes, and to prevent penetration by a maximum credible fire and/or explosion. It is designed to meet Category I structural requirements.

Major Equipment. Facility equipment, including decontamination equipment, fire protection systems, radiation monitoring systems, and drum handling equipment, is identical to that discussed in Section 4.4.4.4.

Shielding and Handling Requirements. Shielding and handling requirements for packaging without treatment are expected to be about the same for the facility at the MOX FFP as for the facility for LLW at the FRP (see-Section 4.4.7.4).

4.4.7.5. Operating and Maintenance Requirements for Packaging Without Treatment at the Mixed Oxide Fuel Fabrication Plant

Because of the rather low volume of waste to be processed, the facility only operates on a single shift and intermittently as needed. Maintenance requirements are expected to be minimal since very simple equipment is involved and since no appreciable contamination of such equipment is expected. Contact maintenance would be used.

Staffing. Table 4.4.74 gives estimated staffing requirements for packaging without treatment at the MOX FFP.

TABLE 4.4.74. Staffing Requirements for Packaging Without Treatment at the Mixed Oxide Fuel Fabrication Plant

<u>Job Description</u>	<u>Personnel Required, man-yr/yr</u>
Operators	1.0
Radiation monitors	0.5
Maintenance craftsmen	0.1

Supplies and Utilities. Table 4.4.75 shows the supplies used in packaging without treatment at the MOX FFP. Table 4.4.76 lists the utility requirements for the facility.

TABLE 4.4.75. Supply Requirements for Packaging Without Treatment at the Mixed Oxide Fuel Fabrication Plant

<u>Material</u>	<u>Use</u>	<u>Annual Requirement</u>
55-gal steel drums	Packaging combustible trash	1050
80-gal steel drums	Packaging ventilation filters	350
Wooden pallets	Palletizing waste drums	470

TABLE 4.4.76. Utility Requirements for Packaging Without Treatment at the Mixed Oxide Fuel Fabrication Plant

Utility	Use Rate	Annual Requirement
Electricity	40 kW	5×10^4 kWh

4.4.7.6 Secondary Waste from the Facility for Packaging Without Treatment at the Mixed Oxide Fuel Fabrication Plant

Secondary wastes produced by packaging without treatment at the MOX FFP are shown in Table 4.4.77. This secondary waste is packaged by this facility and is part of the total MOX FFP secondary waste that is the feed for this facility (Table 4.4.56).

TABLE 4.4.77. Secondary Wastes from Packaging Without Treatment at the Mixed Oxide Fuel Fabrication Plant

Description	Annual Volume, m^3/yr	Radioactivity Factor ^(a)
Combustible and Compactable Waste	3.2	1×10^{-6}

a. Fraction of input activity (Table 4.4.57) in secondary waste.

4.4.7.7 Emissions from the Facility for Packaging Without Treatment at the Mixed Oxide Fuel Fabrication Plant

Facility emissions are shown in Table 4.4.78. Emission routes for the MOX FFP facility for packaging without treatment are the same as those for FRP packaging without treatment facilities, and facility release factors are based on the same assumptions (see Section 4.4.3.7).

TABLE 4.4.78. Emissions from the Facility for Packaging Without Treatment at the Mixed Oxide Fuel Fabrication Plant

Emission	Description	Annual Volume	Radioactivity Release Factor to Atmosphere ^(a)
Gaseous	Ventilation air	$1.6 \times 10^7 m^3$	1×10^{-18}
	Minor accident integrated annual release		1×10^{-17}
Other	Heat (released to ventilation air)	4.2×10^1 MW-hr (1.4×10^8 BTU)	

a. Fraction of total input (Table 4.4.57) released to atmosphere. Includes DF of 10^7 from APS. Released over 365 days/yr.

An estimate of the integrated annual release due to minor accidents (Section 4.4.7.9) for MOX facility is included in Table 4.4.78. It was developed by weighing the minor accident releases by their expected frequencies and summing the quantities for all identified minor

accidents. In addition, a contingency was included in the integrated release to account for unidentified minor accidents and to compensate for the uncertainty in expected frequency information. Estimated integrated annual releases due to minor accidents for this technology are seen in Table 4.4.78 to be larger than the estimated operational releases.

4.4.7.8 Decommissioning Considerations for the Facility for Packaging Without Treatment at the Mixed Oxide Fuel Fabrication Plant

Decommissioning considerations for the MOX FFP facility for packaging without treatment are the same as those discussed in Section 4.4.4.8.

4.4.7.9 Postulated Accidents for Packaging Without Treatment at the Mixed Oxide Fuel Fabrication Plant

Postulated minor accidents for MOX FFP facility for packaging without treatment are given in Table 4.4.79. The basis for estimating releases and frequency of occurrence is the same as discussed in Section 4.4.3.9 for the ILW facility at the FRP.

No accidents that could be classified as severe accidents could be realistically postulated for this technology.

TABLE 4.4.79. Minor Accidents for Packaging Without Treatment at the Mixed Oxide Fuel Fabrication Plant

Accident No. and Description	Sequence of Events	Safety System	Release
4.4.6 - Ruptured waste bags spilled to floor; expected frequency 0.4/yr.	<ol style="list-style-type: none"> 1. Pallet of drums being transferred by fork-lift truck. 2. Drums are dropped, rupturing some of them. 3. Some of the waste bags break, spilling contents on floor. 	<ol style="list-style-type: none"> 1. Spray-wash capability allows decontamination of spill. 	None.
4.4.7 - Fire in barrel of bagged trash; expected frequency 0.02/yr.	<ol style="list-style-type: none"> 1. One open drum of bagged trash ignites and burns. 	<ol style="list-style-type: none"> 1. Only one drum open at a time so fire is limited to one drum. 2. Extensive fire protection section would quickly extinguish a slow burning trash fire in a drum. 3. Spray-wash would decontaminate area. 	1×10^{-5} of radionuclides in the general trash shown in 55-gal drums in Table 4.4.73 released to drumming area filters.
4.4.8 - Spent HEPA filters spilled to floor; expected frequency 0.01/yr.	<ol style="list-style-type: none"> 1. Pallet of drums being transferred by fork-lift truck. 2. Drums are dropped, rupturing one or more of them. 3. HEPA filter spills to floor, breaking plastic bag it is in. 	<ol style="list-style-type: none"> 1. Spray-wash capability allows decontamination of spill. 	3×10^{-6} of the activity on ventilation filters in 80-gal drums shown in Table 4.4.73 released to drumming area filters.

4.4.7.10 Costs for the Facility for Packaging Without Treatment at the Mixed Oxide Fuel Fabrication Plant

Estimates have been made, in mid-1976 dollars, of capital, operating, and leveled unit costs. A complete description of the cost estimate bases, assumptions, and definitions is given in Section 3.8.

Capital Costs. The capital cost estimate for the MOX FFP facility for packaging without treatment is shown in Table 4.4.80. The estimate covers all capital costs specifically resulting from inclusion of the facility as an integral part of the reference MOX FFP (see Section 3.2.4). These costs also include the effect of incremental additions to utilities, such as electrical substation; compressed air; and heating, ventilation, and air conditioning (HVAC); as well as the cable, piping and other bulk materials incorporated directly into the packaging without treatment facility. However, general MOX FFP costs for such services as laboratories and warehousing are not allocated to the reference facility.

TABLE 4.4.80. Capital Cost Estimate for the Facility for Packaging Without Treatment at the Mixed Oxide Fuel Fabrication Plant

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		1	200		200
Buildings and structures		32	200	400	600
Bulk materials		7	300	100	400
Site improvements		—	—	—	—
Subtotal of direct site construction costs		40	700	500	1200
Indirect site construction costs	10	8	200	200	400
Total field cost	10	48	900	700	1600
Architect-Engineer services					300
Subtotal					1900
Owner's cost					600
Total facility cost					2500
Estimate accuracy range					±25%

The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation with the exception of working capital and the cost of shipping containers (steel drums) primarily for use offsite.

Operating Cost. Table 4.4.81 lists the operating cost components for MOX FFP packaging without treatment. Direct labor costs are based on manpower requirements given in Table 4.4.74.

TABLE 4.4.81. Operating Cost Estimate for Packaging Without Treatment at the Mixed Oxide Fuel Fabrication Plant

<u>Cost Elements</u>	<u>Annual Costs, \$1000s</u>
Direct labor	30
Process materials	30
Utilities	0
Maintenance materials	4
Overhead	33
Miscellaneous	8
Total	105 +50% -25%

Process materials and utilities costs are based on requirements given in Tables 4.4.75 and 4.4.76. Maintenance materials costs are estimated at 3% of initial major equipment costs. Overhead and miscellaneous costs are calculated in the standard manner described in Section 3.8.

Levelized Unit Cost. The total levelized unit cost including the levelized capital and operating components is given in Table 4.4.82. The cost calculation assumes private ownership of the facilities and a 15-year economic life.

TABLE 4.4.82. Levelized Unit Cost Estimate for Packaging Without Treatment at the Mixed Oxide Fuel Fabrication Plant

<u>Cost Element</u>	<u>Unit Cost, \$/kg HM(a)</u>
Levelized capital charge	1.55
Levelized operating charge	.25
Levelized total unit cost	1.80 ±35%

a. Dollars per kg HM MOX fuel. To convert to \$/kg HM reprocessed, divide by five.

4.4.7.11 Construction Requirements for the Facility for Packaging Without Treatment at the Mixed Oxide Fuel Fabrication Plant

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating this impact.

Project Schedules and Construction Manpower. The schedule for engineering, procurement, and construction of the facility for packaging without treatment is an integral factor in the overall schedule for the MOX FFP (given in Section 3.2.3). The field labor force estimated for the construction of the facility is tabulated below:

4.4.109

	Man-hours, 1000s
Manual field labor	48
Nonmanual field labor	<u>10</u>
Total field labor	58

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials and services provided at the site of the MOX FFP, while offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is as shown below:

	Costs, 1000s
Onsite	800
Offsite	<u>1700</u>
Total	2500

Site Requirements. No site requirements beyond those for the MOX FFP are identifiable for the reference facility for packaging without treatment. Land commitments for the facility are included with those of the MOX FFP.

Water. Approximately 800 m^3 (0.2×10^6 gal) of water are required during the construction period.

Construction Materials. Materials committed to facility construction are:

Concrete	450 m^3	(600 yd^3)
Steel	90 MT	(100 tons)
Copper	2.7 MT	(3 tons)
Zinc	0.9 MT	(1 ton)
Aluminum	0.9 MT	(1 ton)
Lumber	25 m^3	(10 MFBM)

Energy. Energy resources used during construction are:

Propane	7.6 m^3	(2,000 gal)
Diesel fuel	76 m^3	(20,000 gal)
Gasoline	45 m^3	(12,000 gal)
Electricity:		
Peak demand	70 kW	
Total consumption	45,000 kWh	

Transportation Requirements. No transportation requirements for the packaging without treatment facility have been identified beyond those for the MOX FFP.

4.4.7.12 Effects of Fuel Cycle Options on Packaging Without Treatment at the MOX FFP

The reference process for packaging waste without treatment at the MOX FFP assumes reprocessing of LWR fuel and recycling the recovered uranium and plutonium. The fuel cycle options, 1) no recycle, 2) uranium recycle only with plutonium to a repository, and 3) uranium recycle only with plutonium to the high-level waste, would all eliminate the MOX FFP and the need for a facility to package its combustible waste.

4.4.8 Other Compactable and Combustible Waste Treatment Alternatives at the Mixed Oxide Fuel Fabrication Plant

Incineration and packaging without treatment of MOX FFP compactable and combustible wastes have been discussed in Sections 4.4.6 and 4.4.7, respectively. Other alternatives to these two approaches are the same as the alternatives for treating the corresponding waste at the fuel reprocessing plant (see in Section 4.4.5).

Since the annual waste production at the MOX FFP is smaller than at the FRP, a greater incentive may be present at the MOX FFP to replace incineration with a process better adapted to a smaller scale operation. The compaction and packaging process and the acid digestion process are both alternatives that might be more easily adapted to the MOX FFP scale of operation. On the other hand, because of the rather high plutonium content of the waste at the MOX FFP, use of a process that renders the plutonium readily recoverable may be desirable. Only the incineration and acid digestion processes satisfy this criterion. As the acid digestion process undergoes further development, it may prove to be a very competitive process for treating combustible wastes at a MOX FFP. It should be noted, though, that none of the processes available for treating spent ventilation filters converts the plutonium to a readily recoverable form.

4.4.9 Safeguard Requirements for Compactable and Combustible Waste Treatment

Compactable and combustible wastes are not attractive targets for theft or sabotage, largely because the concentrations of special nuclear material and other radioactive material would be very low. Such wastes are not a practical source of strategic nuclear material and most are not a significant radiological health hazard. The concentration of radioactivity of the materials is several orders of magnitude below that of spent fuel. The attractiveness of this waste is reduced further by the wide range of radioactive material types and concentrations possible for each container, making theft and sabotage results somewhat unpredictable.

Compacted, process ventilation filters from the MOX fuel fabrication plant, could produce drums containing up to 200 g of Pu per drum. Fifty drums per year of such wastes could be expected as a part of a total of 2100 drums of waste per year from the MOX plant. All waste drums would be stored together for eventual emplacement in a geologic repository. If the spent filters are not compacted during the preparatory steps, up to seven times as many drums (350 per year) would be required. A corresponding lesser amount of Pu would be in each drum. While the total quantity of Pu stored in this waste is significant, the specific drums containing Pu would be unidentified and randomly distributed among all of the drums of various waste types. This would result in a target considered to be too diffuse for theft for use in a weapon assembly or for sabotage by dispersal. If the drums containing plutonium-contaminated filters are identifiable, special safeguards measures would be required during processing and interim storage.

Compactable and combustible wastes will be within the safeguarded facilities of the FRP or MOX FFP sites during treatment and packaging. Because these wastes may contain some plutonium, they would be protected against industrial sabotage and theft in accordance with the requirements of 10 CFR 73.40.⁽¹⁹⁾

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4.5 DEGRADED SOLVENT TREATMENT

4.5 DEGRADED SOLVENT TREATMENT

A solvent extraction process is typically used in a fuel reprocessing plant (FRP) to separate uranium and plutonium products from the other radionuclides present in dissolved irradiated nuclear fuel. The organic solvent commonly used contains about 30% tributyl phosphate (TBP) in a kerosene or other normal paraffin hydrocarbon diluent. This solvent is slowly degraded by chemical and radiation damage, causing a gradual loss in extractant effectiveness. As a result, the typical FRP uses solvent treatment cycles in which the solvent is routinely and continuously treated with chemicals to remove degradation products and radioactive impurities. This treatment normally involves sequentially washing the solvent with sodium carbonate and nitric acid solutions.

Small amounts of entrained organic solvent from the solvent extraction columns, however, can sometimes accumulate in vessels intended for aqueous solutions. Solvent leaks into sumps can also be expected. In such instances, solvent degradation may proceed to the extent that attempted cleanup in the normal solvent treatment systems would be undesirable and the solvent would be discarded. It is possible that normal solvent treatment systems would be incapable of adequately removing degradation products from a major portion of the plant solvent inventory; however, such situations are expected to occur infrequently. With some process flowsheets, excess solvent may be added for process reasons. Under such circumstances, if more solvent is added than is compensated for by normal losses, a small quantity of the solvent may be routinely discarded.

It is anticipated that the quantity of degraded solvent requiring treatment for disposal can be limited to less than $16 \text{ m}^3/\text{yr}$ (4200 gal/yr) for a 2000-MTHM/yr FRP. Degraded solvent intended for disposal usually has several times the normal radioactivity level of washed solvent.

4.5.1 Degraded Solvent Incineration

Incineration is the primary choice for disposal of degraded solvent and the one for which technology is well established. The degraded solvent is a contaminated liquid waste that is not readily evaporated and is not particularly compatible with other intermediate-level liquid waste solidification methods.

Since the organic to be disposed of constitutes a small volume stream, a logical approach to its incineration is to combine it with other, much larger volume streams to be incinerated or calcined. Inclusion in the feed to combustible trash incinerators or in the feed to high-level waste calcination are possible approaches to degraded extractant disposal. These options are treated in Sections 4.4 and 4.1, respectively. In the event that neither of these options is available (i.e., incineration is not chosen for combustible trash disposal and high-level waste calcination is not available), a separate solvent incinerator becomes necessary. Only incineration designed specifically for the degraded solvent is discussed in this section.

4.5.2

4.5.1.1 Alternative Solvent Incineration Processes

In its simplest form, degraded solvent incineration can be performed by open pan burning, as was done at the Savannah River Plant.⁽¹⁾ From 1955 to 1964, about 650 m³ (1.7 x 10⁵ gal) of degraded solvent (30% to 50% TBP in kerosene diluent) was burned outdoors in open pans. Various pan configurations were used, including relatively shallow dishes (15 to 30 cm deep), deep rectangular vessels, and longitudinal halves of 1.5-m³ (400 gal) cylindrical tanks. Following the initial light-off, gravity provided a continuous degraded solvent feed from an above-ground tank through a device to prevent flashback. Although no off-gas treatment was used, radionuclide releases were acceptably low; decontamination factors of between 10³ and 10⁴ were experienced. This method of degraded solvent incineration was eventually discontinued in 1971.

Quiescent burning, such as in an open pan, typically produces an off-gas that is low in entrained material, unless a volatile noncombustible liquid (e.g., water) is inadvertently added to the burning solvent. The capital and operating costs are lower for open pan burning than for any other method of degraded solvent incineration. However, this method has fallen into disfavor because of the production of copious quantities of black smoke, the pan corrosion problems (for both mild steel and stainless steel) caused by water accumulating to form phosphoric acid, and the need for suitable disposal of failed pans and pans filled with incineration residues.

A smokeless solvent incinerator⁽²⁾ is being developed at the Savannah River Plant to replace the previously used open pan burning method. Because of the high decontamination factor for radionuclides with quiescent burning, the design includes a quiescent pan burner for the first stage of the incinerator. Nonradioactive tests using 30% to 50% TBP in kerosene show that smokeless burning can be achieved by burning the off-gases from the first stage in an auxiliary-fired forced-draft incinerator. A scrubber is needed to remove the phosphate emissions that result from burning TBP.

Degraded solvent is fed to an open pan contained in the first stage of the refractory-lined steel incinerator, where it is ignited by a pilot burner. Air provided by a blower supplies the required oxygen for the reaction and controls the reaction temperature. Burning proceeds through combustion of gases volatilized from the quiescent liquid surface, thus leaving behind nonvolatile solutes and organic polymers. The gases are carried into the second-stage burner, operated at 1100°C (2000°F) by combustion of auxiliary fuel, to complete the oxidation of organic vapors and unburned carbon. The off-gas from the second-stage burner is routed to a quench tank and scrubber, where it is cooled and the P₂O₅ from combustion of TBP is removed as phosphoric acid. The contaminated scrub water and the water-soluble residue left in the burner pan are sent to the low-activity liquid waste tanks for further treatment. Anticipated problems with this system include removal and disposal of residues formed in the first stage and carbon buildup on the first-stage incinerator walls, which could affect burning characteristics.

The two degraded solvent incineration methods previously used or proposed for future use at the Savannah River Plant both use quiescent burning to provide all or nearly all of the required radioactive material decontamination of off-gases. An alternative approach is to

4.5.3

atomize the organic liquid feed stream to the incinerator. This method has the potential advantage of avoiding problems in removal and disposal of residue from the combustion chamber but the potential disadvantage of requiring an off-gas treatment system for capture of radionuclides and other noxious pollutants. An incinerator system of this type has been installed at the Allied-General Nuclear Services Company's Barnwell Nuclear Fuel Plant at Barnwell, South Carolina.⁽³⁾ Similar systems are commercially available.

The Barnwell Nuclear Fuel Plant degraded solvent incinerator serves as a basis for the facility description here. This concept was chosen because it is an example of a system designed specifically for degraded solvent incineration at a commercial FRP. The reference facility design is an adaptation of available industrial designs for nonnuclear applications. The reference facility is a forced-convection incineration unit as opposed to a quiescent oil burner. Selection of this incinerator type for the reference facility does not necessarily imply that other incinerator systems that could be used have operational, economic, or environmental disadvantages.

4.5.1.2 Solvent Incineration Facility Design Basis

The following assumptions were made in the design of the reference facility:

- The designed solvent incinerator will have a capacity of 85 m³ of organic per year on a 24-hr/day, 7-day/week, 300-day/yr basis.
- The facility will be located within a 2000-MTHM FRP operation. All supporting facilities and services will be part of the reprocessing plant. Although the direct operation of the solvent incinerator is treated separately here, its operation, including manpower requirements, would be closely integrated with the main FRP operation.
- The solvent incinerator facility will receive for disposal 16 m³ (4200 gal) of degraded extractant per year.
- The extractant will be burned in the incinerator and water will be used to scrub out the phosphorous pentoxide resulting in phosphoric acid, which will then be sent to the intermediate-level waste concentrators.
- The solvent incinerator will be designed to operate most efficiently on a 24-hr basis; therefore, the incinerator is best operated on a campaign basis (55 days/yr).
- The facility will be equipped with instrumentation to automatically shut down the facility in a safe manner if flame-out or power loss occurs.

4.5.1.3 Solvent Incineration Facility Process

A schematic flowsheet for the solvent incineration facility is shown in Figure 4.5.1. The solvent batch stripping tank is the initial collection point for degraded solvent disposal. Degraded solvent batches collected in the batch stripping tank will be washed repeatedly with sodium carbonate and nitric acid solutions to minimize the radionuclide content of the organic liquid to be incinerated; oxalic acid and caustic wash solutions may be used occasionally.

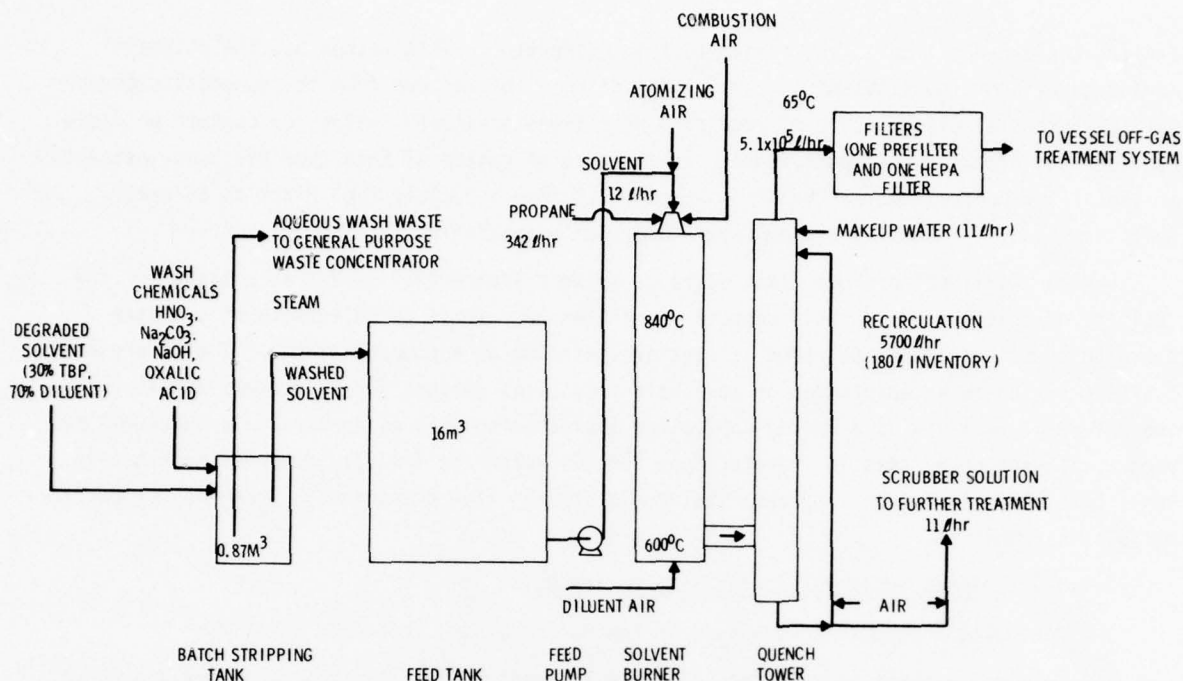


FIGURE 4.5.1. Solvent Incineration Facility Flowsheet

Following this decontamination step the organic phase is estimated to have the radionuclide content shown in Table 4.5.1. The organic phase is transferred into the solvent burner feed tank, and the aqueous phase is routed to a general purpose waste concentrator. Normally, operation of the solvent burner will be initiated when the feed tank inventory reaches about 12 m^3 (3200 gal).

The degraded solvent is fed to the solvent burner from the feed tank by a positive-displacement, fixed-rate pump. The burner nozzle is positioned at the top of the combustion chamber and directed downward. The nozzle has separate fuel ports for propane and waste solvent. The combustion air is also supplied through the burner nozzle. The various air inputs to the solvent burner are provided by a direct-drive turbo blower driven by a 15-hp electric motor. Air requirements are categorized as follows: (1) combustion air introduced through a port in the burner nozzle, (2) atomizing air entering through the nozzle with the degraded solvent to convert it into a fine spray, (3) diluent air added near the bottom exit point of the combustion gases to reduce temperature from 840°C (1544°F) to below 600°C (1112°F), (4) liner purge air fed between the stainless steel liner and the Inconel combustion chamber to ensure that no flammable gases accumulate within the liner, (5) flame detector purge air to provide cooling and prevent combustion around the two flame detector elements, and (6) pilot light air for proper burning of the propane-fueled pilot lights. Extensive solvent burner automatic shutdown and alarm instrumentation is included in the design to minimize the potential hazards of abnormal operating conditions.

The solvent burner is started by bringing the combustion chamber to an operating temperature of 840°C (1544°F). This is accomplished by slowly increasing the flow of propane to the burner. After the operating temperature is reached and stabilizes, the degraded solvent flow

TABLE 4.5.1. Activity in FRP Degraded Extractant^(a,b)

	<u>Ci/yr</u>
<u>Fission Products</u>	
¹²⁹ I	0.007
⁹⁰ Sr + ⁹⁰ Y	0.024
⁹⁵ Zr + ⁹⁵ Nb	22
¹⁰⁶ Ru + ¹⁰⁶ Rh	760
¹³⁴ Cs + ¹³⁷ Cs + ^{137m} Ba	0.060
¹⁴⁴ Ce + ¹⁴⁴ Pr	0.096
All other FPs	0.020
Total	782
<u>Actinides</u>	
²³⁹ Pu	72
²⁴¹ Pu	3.5×10^4
Other Pu	1.2×10^3
²⁴² Cm + ²⁴⁴ Cm	34
All other actinides	1.8
Total	3.6×10^4

a. Based on waste characterization Table 3.3.33, assuming uranium and plutonium recycle, 2000 MTHM/yr reprocessed 1.5 yr out of ₃ reactor.

b. Volume = 16 m³/yr.

is started to the burner nozzle. The propane burns as a hollow cone, and the degraded solvent burns within that cone. The propane flow is controlled by the temperature of the combustion chamber. As the flow of degraded solvent increases and the temperature of the combustion chamber increases, the flow of propane automatically decreases to a predetermined minimum. This minimum flow of propane is maintained to ensure that a flame would continue if the degraded solvent flow is interrupted. This feature allows a mixture of solvent and aqueous solutions, or even a totally aqueous solution, to be fed to the burner without shutting the unit down.

Gases leaving the solvent burner consist of the normal combustion products (carbon dioxide, water vapor, nitrogen, unreacted oxygen, etc.), P₂O₅ aerosol from TBP combustion, and small amounts of particulate and volatilized radioactive compounds. These gases are passed through a quench tower to reduce gas temperatures and to scrub the majority of the contaminants from the gas. Scrubber solution is circulated through the quench tower at about 95 l/min (25 gpm) by an airlift. Another airlift continuously removes a small flow of scrubber solution under specific gravity control to a general purpose waste concentrator. Makeup water is continuously added to

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the scrubber solution under level control in the bottom section of the quench tower to compensate for the scrubber solution removal and evaporation. [The quench tower is designed to cool 8500 ℓ /min (300 scfm) of combustion gases and diluent air from about 600°C (1100°F) to 65°C (150°F).] The off-gases in the quench tower pass through a 4-in. stainless steel York-type mist eliminator within the tower and are then routed through a gas heater, a prefilter, and a HEPA filter before entry into the vessel off-gas treatment system. Makeup water enters above the mist eliminator pad for cleaning purposes.

4.5.1.4 Solvent Incineration Facility Description

The facilities for solvent incineration are located in the intermediate-level cell of the main fuel reprocessing plant. These facilities include process equipment for treatment of the off-gas and aqueous wash solutions. Service and support activities are integrated with the FRP. Figure 4.5.2 is a plan and section drawing for the solvent incineration facilities. This drawing includes views showing the extent and arrangement of building spaces required within the FRP for operating, service, and support areas associated with the solvent incinerator process.

The major items of process equipment for solvent incineration are located in an independent intermediate-level cell. Approximately 650 m^3 (23,000 ft^3) of cell space are required. In addition, the solvent burner feed pump is located in a small adjacent niche with access to the maintenance gallery.

Major Equipment. Major equipment includes a 0.9- m^3 (230-gal) solvent batch stripping tank. The tank is about 1 x 1.5 m (3 x 5 ft) and is constructed of 304L stainless steel; it includes provisions for heating or cooling (lower section jacketed), introduction of chemical wash solutions, agitation of tank contents, and sampling. The solvent burner feed tank is 2.4 m (8 ft) in diameter and 3.4 m (11 ft) tall; it is made of 304L stainless steel and has a capacity of about 16 m^3 (4300 gal). Tank sampling capability is provided to allow additional laboratory analyses of solvent burner feed material.

Figure 4.5.3 shows the solvent burner. The combustion chamber is lined with Inconel and surrounded by 10 cm (4 in.) of castable refractory insulation and a 304L stainless steel outer jacket. Solvent burner outer dimensions are about 1 m (3 ft) in diameter by 4.6 m (15 ft) long.

Figure 4.5.4 shows the quench tower. The combustion chamber off-gases are fed into the solvent burner quench tower about 1 m (3 ft) from the bottom via a vent line 20 cm (8 in.) in diameter. The quench tower is a cylindrical vessel about 0.6 m (2 ft) in diameter by 5 m (17 ft) tall. The bottom 0.6 m (2 ft) of this vessel serves as a reservoir for about 180 ℓ (47 gal) of recirculating aqueous scrubber solution. The lower 1.8 m (6 ft) of the quench tower is surrounded by a stainless steel cooling jacket. The upper portion contains ten decks of chevron plates to promote intimate gas-liquid contact. Alternate decks are rotated (about 1.6 radians or 90°) and are spaced about 30.5 cm (12 in.) apart. A liquid distributor located in the top of the quench tower prevents liquid channeling.

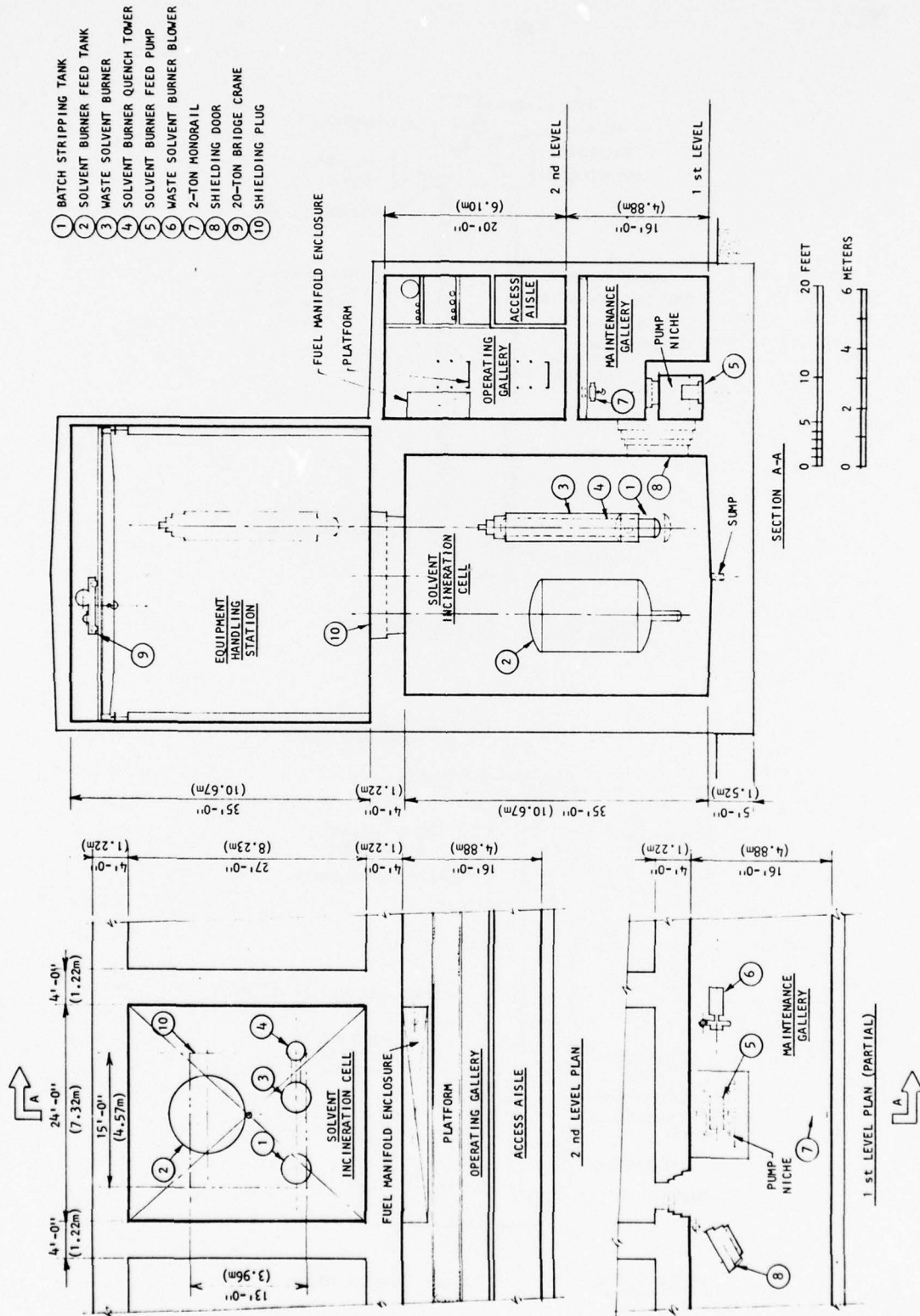


FIGURE 4.5.2. Solvent Incineration Facility's Plan and Section Drawing

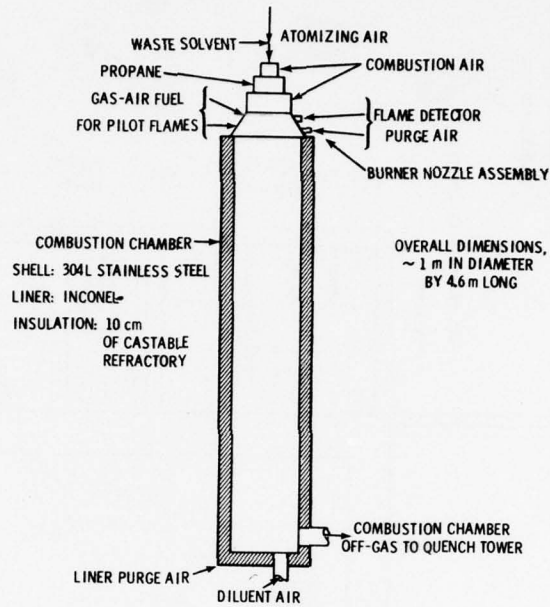


FIGURE 4.5.3. Solvent Burner

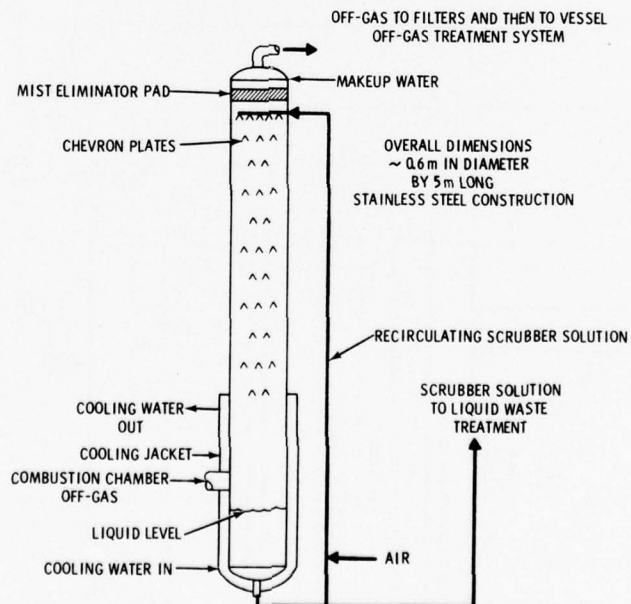


FIGURE 4.5.4. Solvent Burner Quench Tower

Shielding and Remote Handling Equipment. The cell provides radiation shielding and radioactive material confinement during plant operations. Maintenance work on cell equipment will be done by contact methods requiring personnel entry rather than by remotely operated tools.

4.5.1.5 Solvent Incineration Facility Operating and Maintenance Requirements

The only unusual maintenance requirement results from an estimated ten-year lifetime for the solvent burner. The solvent burner would probably be replaced in its entirety.

The solvent incinerator would probably be operated on a campaign basis. Incineration of the projected $16 \text{ m}^3/\text{yr}$ (4200 gal) of degraded solvent would require 55 days/yr (24-hr basis) of operation. Because of the time required for startup (time to get the solvent burner up to operating temperature), it will be more efficient to operate on a 24-hr basis during individual campaigns.

Staffing. Staffing requirements for solvent incineration are minor. During actual incinerator operation (55 days/yr) about 25% of one operator's time would be required to monitor system operations.

Utilities. Utility requirements for solvent incineration are given in Table 4.5.2.

TABLE 4.5.2. Solvent Incineration
Utility Requirements

Utility	Use Rate	Annual Requirement
Electricity	15 kW	2×10^4 kWh
Propane (gaseous)	$8 \text{ m}^3/\text{day}$ (STP)	450 m^3 (STP)
Air	$1.2 \times 10^4 \text{ m}^3/\text{day}$ (STP)	$6.8 \times 10^5 \text{ m}^3$ (STP)
Water consumed	$6 \text{ m}^3/\text{day}$	330 m^3

4.5.1.6 Solvent Incineration Facility Secondary Radioactive Wastes

Secondary wastes from the solvent incineration facility consist almost entirely of blow-down liquid from the quench tower. This consists of $15 \text{ m}^3/\text{yr}$ (4000 gal/yr) of 10 wt% H_3PO_4 solution containing virtually all the radionuclides present in the degraded solvent incinerated. This waste will be routed to the FRP general purpose intermediate-level waste liquid concentrators.

It is expected that the off-gas filters will be changed no more than twice per year. This procedure will generate at most about 0.1 m^3 (3.5 ft^3) of uncompacted filter media, the disposition of which is discussed in Section 4.4. Any contact maintenance activities will also generate small amounts of combustible trash (see Section 4.4).

4.5.1.7 Solvent Incineration Facility Emissions

Table 4.5.3 gives the radioactive and nonradioactive releases from the solvent incineration facility.

TABLE 4.5.3. Solvent Incineration Facility Emissions

Emission	Description	Annual Quantity	Radioactivity Release Factor to Atmosphere(a)
Gaseous	Incinerator off-gas	Air $6.8 \times 10^5 \text{ m}^3$	^{129}I 1×10^{-3}
		NO_x 20 kg	All other 1×10^{-13}
		CO 10 kg	
	Minor accident integrated annual release		None identified
Cooling tower water:	• evaporated ($T = 38^\circ\text{C}$)	$2.8 \times 10^5 \text{ kg}$	
	• drift ($T = 38^\circ\text{C}$)	$1.3 \times 10^3 \text{ kg}$	
	• blowdown ($T = 27^\circ\text{C}$)	$4.8 \times 10^4 \text{ kg}$	
Other	Heat	1.9×10^2	
		$(6.4 \times 10^8 \text{ BTU})$	

a. Fraction of input activity (Table 4.5.1) released to atmosphere. Includes DFs obtained in vessel off-gas system as well as in APS system. Released over 55 days/yr.

4.5.1.8 Solvent Incineration Facility Decommissioning Considerations

The expected useful life of the solvent burner is ten years. The other equipment associated with the solvent incineration system is expected to have a useful life equal to that of the overall plant. No appreciable radioactivity buildup in the equipment is expected.

4.5.1.9 Solvent Incineration Facility Postulated Accidents

As noted in Section 4.5.1.3, the solvent burner will be located in the intermediate-level cell of the FRP. This equipment will be instrumented and will have interlocks for shutdown in case of power loss or abnormal operation (overheating, etc.). The operator will be trained to take proper corrective actions in case of abnormal operating conditions.

Postulated minor and moderate accident scenarios for the solvent incineration facility are given in Tables 4.5.4 and 4.5.5. Of the accidents described, loss of normal electrical power and flameout and explosive reignitions have occurred in nonnuclear facility incinerators.

TABLE 4.5.4. Solvent Incineration Facility Minor Accidents

Accident No. and Description	Sequence of Events	Safety System	Release
4.5.1 - Loss of normal electrical power. Expected frequency ~1/yr.	Power to substation supplying facility interrupted or failure of facility circuitry.	Interlocks provided in instrumentation and control system ensure that fuel flow is shut off whenever power failure occurs, resulting in automatic and safe facility shutdown.	None.

TABLE 4.5.5. Solvent Incineration Facility Moderate Accidents

Accident No. and Description	Sequence of Events	Safety Systems	Release
4.5.2 - Flameout followed by explosive reignition. Expected frequency $\sim 0.001/\text{year}$.	<ol style="list-style-type: none"> 1. Solvent burner flame goes out. 2. Re-ignition of an explosive mixture of propane, atomized solvent, and air. 	<ol style="list-style-type: none"> 1. Instrumentation includes fail-safe flame detectors in combustion chamber. 2. Whenever flame is not detected, the solvent burner is shutdown, including closure of automatic fast-acting solenoid valves on waste solvent and propane supply lines. 3. Any unburned fuel in solvent burner is rapidly removed by flowing air. 	6×10^{-9} of annual feed activity (see Table 4.5.1). released to cell HEPA filters.
4.5.3 - Accidental solvent fire. Expected frequency $\sim 0.001/\text{year}$.	<ol style="list-style-type: none"> 1. Leakage or bursting of pressurized solvent burner feed pipe. 2. Ignition of leaking solvent. 3. Due to smoke, cell filters plug then fail. 	<ol style="list-style-type: none"> 1. Feed lines instrumented for flow rates so that only small leaks would escape immediate detection. 2. Sump level alarm would alert operators to accumulated leakage. 3. Ignition sources (flashpoint $\sim 70^\circ\text{C}$) are absent. 4. FRP-APS HEPA filters ($DF=10^4$) would contain most of the material released in a fire. 	$<10^{-5}$ of annual activity (see Table 4.5.1) released to FRP APS filters.
4.5.4 - Explosion in incinerator. Expected frequency $\sim 0.001/\text{year}$.	<ol style="list-style-type: none"> 1. An explosive liquid, "red oil," is formed in degraded solvent. 2. An accumulation of this explosive liquid in the incinerator results in an explosion. 	<ol style="list-style-type: none"> 1. Solvent washing procedure minimizes possible accumulation of "red oil" in the solvent. 2. Accumulation of liquid in the incinerator is prevented by controls that shut off flow to burner if temperature is below that required to completely burn atomized feed. 3. Facility HEPA filters ($DF=10^7$) would contain most of the nuclides released from an exploding incinerator. 	6×10^{-9} of annual feed activity (see Table 4.5.1) released to cell HEPA filters.

4.5.1.10 Solvent Incineration Facility Costs

Estimates have been made, in mid-1976 dollars, of capital, operating, and levelized unit costs. A complete description of the cost estimate bases, assumptions, and definitions is given in Section 3.8.

Capital Costs. The capital cost estimate is shown in Table 4.5.6. This estimate covers all capital costs resulting from the inclusion of the solvent incineration facility as an integral part of the FRP described in Section 3.2. Also included are any required incremental additions to facilities for supply of electricity, compressed air, propane, or other utilities and any incremental additions to instrumentation, piping, etc. However, general capital costs for such services as laboratories, warehousing, shops, etc., are not allocated to the solvent incinerator facilities.

The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation, with the exception of working capital.

TABLE 4.5.6. Capital Cost Estimate for Solvent Incineration Facility

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		8	600	100	700
Buildings and structures		70	400	800	1200
Bulk materials		47	500	600	1100
Site improvements		5	40	60	100
Subtotal of direct site construction costs		130	1540	1560	3100
Indirect site construction costs	34	24	500	800	1300
Total field cost	34	154	2040	2360	4400
Architect-engineer services					800
Subtotal					5200
Owner's cost					1600
Total facility cost					6800
Estimate accuracy range					±30%

Operating Cost. Costs of materials for the solvent treatment process are negligible. Maintenance materials costs are estimated at 2% of major equipment plus a \$3000 annual accrual to replace the refractory or the entire solvent burner every ten years. Miscellaneous costs include a \$0.05 per gallon charge for concentration of blowdown waste from the incinerator. Table 4.5.7 summarizes the operating costs.

Levelized Unit Cost. The levelized unit cost, including levelized capital and operating costs, is shown in Table 4.5.8. The unit cost calculation assumes private ownership of the facilities and a 15-year economic life.

4.5.1.11 Solvent Incineration Facility Construction Requirements

Factors relating to site preparation and facility construction will have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating the impact of construction activities.

TABLE 4.5.7. Solvent Incineration Facility Operating Cost Estimate

<u>Cost Element</u>	<u>Annual Costs, \$1000s</u>
Direct	2.5
Process materials	negligible
Utilities	0.5
Maintenance materials	17
Overhead	13
Miscellaneous	21
Total	54 ^{+50%} -25%

TABLE 4.5.8. Solvent Incineration Facility Levelized Unit Cost Estimate

<u>Cost Element</u>	<u>Unit Cost, \$/kg HM</u>
Levelized capital charge	1.17
Levelized operating charge	0.03
Levelized total unit cost	1.20 $\pm 40\%$

Project Schedules and Construction Manpower. The schedule for engineering, procurement, and construction of the solvent incineration facility is an integral factor in the overall schedule for the FRP. Section 3.2.3 describes this schedule. The field labor force estimated for the construction of the solvent incineration facility is tabulated below:

	<u>Man-hours, 1000s</u>
Manual field labor	154
Nonmanual field labor	34
Total field labor	188

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials, and services provided at the site of the FRP; offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is as follows:

	<u>Costs, \$1000s</u>
Onsite	2500
Offsite	4300
Total	6800

Site Requirements. Land commitments for the solvent incineration facility are included with those of the FRP. Water used during the construction period will be approximately 1900 m^3 (5×10^5 gal).

4.5.14

Construction Materials. Materials committed to facility construction are:

Concrete	900 m ³	(1,200 yd ³)
Steel	220 MT	(240 tons)
Copper	4.5 MT	(5 tons)
Zinc	0.9 MT	(1 ton)
Aluminum	0.9 MT	(1 ton)
Lumber	85 m ³	(36 MFBM)

Energy. Energy resources used during construction are:

Propane (liquid)	17 m ³	(4,600 gal)
Diesel fuel	174 m ³	(46,000 gal)
Gasoline	117 m ³	(31,000 gal)
Electricity		
Peak demand	100 kW	
Total consumption	107,000 kWh	

Transportation Requirements. No separate transportation requirements for the solvent incineration facility have been identified beyond those for the FRP.

4.5.1.12 Effects of Fuel Cycle Options

The reference process for solvent incineration assumes reprocessing of LWR fuel and recycling the recovered uranium and plutonium. The following alternative fuel cycle modes have also been assessed insofar as they relate to solvent incineration.

No Recycle. No solvent extractant is used and no solvent incineration facility is required.

Uranium Recycle Only with Plutonium to a Repository. Solvent extraction will be carried out to recover uranium. This will generate approximately the same amount of degraded extractant as with full uranium and plutonium recycle. The facility design and operation would be virtually the same as with uranium and plutonium recycle.

Uranium Recycle Only with Plutonium to HLW. Insofar as solvent incineration is concerned, this case is exactly the same as that discussed for uranium recycle only with plutonium to a repository.

4.5.2 Other Alternatives for Degraded Solvent Disposal

It is expected that future FRPs may incorporate into the initial facility design either a high-level waste calciner or a solid waste incinerator, or both. In such cases, it is technically feasible to include provision for degraded solvent incineration in either of these equipment items. Despite added operational complexity, economic advantages could result from such multipurpose use, since the combustion and off-gas treatment equipment needed for calcination or solid waste incineration is similar to that needed for degraded solvent incineration. Incineration of solvent along with incineration of general combustible trash is treated further in Section 4.4.1, and incineration in the high-level waste calciner is treated in Section 4.1.2.3.

Absorption of organic liquids in materials such as vermiculite, clays, diatomite, silica gel, Portland cement, calcium sulfate, or plaster of Paris is a well-established technology in the nuclear industry.⁽⁴⁾ After such immobilization, the resulting solids can be treated in a manner similar to noncombustible trash. The solid resulting from such absorption can also be treated further by incorporation in cement.⁽⁵⁾ Limited amounts of organic liquids can be incorporated in cement by adding a dispersing agent.⁽⁵⁾ Aqueous concentrates containing up to 15% dispersed organic liquid have been solidified in this manner.

If solvent is being disposed of only because it is seriously degraded and not because the FRP has an excess due to process reasons, the solvent may be treated more vigorously to restore its usefulness. Although this report estimates that an FRP will need to dispose of up to 16 m³/yr (4200 gal) of degraded solvent, future operating experience or process flowsheet improvements may be sufficiently effective that virtually all the plant solvent can be recycled back into the separations processes.

Alternative solvent purification processes, perhaps more effective than chemical washing, may also be used in the future. Solvent purification by ion exchange, for example, has shown promise in laboratory and small-scale production testing. Solvent purification by distillation has also been considered but has not been extensively developed because of 1) insufficient assurance that the distilled solvent would be reusable and 2) the high capital and operating costs of vacuum distillation systems, which would be preferred over atmospheric pressure distillation systems to prevent thermal solvent degradation.

4.5.3 Safeguard Requirements for Degraded Solvent Treatment

No safeguards are specifically required for degraded solvent. This waste would not be a target for theft or sabotage. It would contain less than 0.01% of the plutonium in spent fuel, or less than 3 kg in an entire year's accumulation. The consequences of theft or sabotage would be essentially negligible. Nevertheless, the treatment processes would probably be carried out within facilities of the FRP, which are safeguarded.

REFERENCES FOR SECTION 4.5

1. D. W. Tharin, Burning of Radioactive Process Solvent. DP-942, Savannah River Laboratory, Aiken, SC, February 1965.
2. Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle. ERDA 76-43, Energy Research and Development Administration, Washington, DC, vol. 2, pp. 9.61 to 9.66, May 1976.
3. Final Safety Analysis Report, Barnwell Nuclear Fuel Plant Separations Facility. Docket No. 50332-41, Allied-Gulf Nuclear Services, Barnwell, SC, pp. 4-74 to 4-79, October 1973.
4. Ref. 2, pp. 12.3 to 12.7.
5. Ref. 2, p. 12.15.

4.6 DILUTE AQUEOUS WASTE PRETREATMENT

4.6 DILUTE AQUEOUS WASTE PRETREATMENT

The initial step in the treatment of most waste streams is often some type of waste concentration process. This process converts the liquid waste feed material into two product streams: 1) a concentrated liquid, slurry, or particulate solid containing the bulk of the radionuclides and nonradioactive chemicals and 2) a purified liquid containing significantly reduced contaminant concentrations. The reduced volume of the concentrated waste permits use of smaller facilities for interim waste storage and waste immobilization, and smaller quantities of waste immobilization additives. In many cases, the purified stream may be recycled to the main process. If recycle is impractical, the purified stream may be discharged to the environment, perhaps after additional treatment processes to reduce the radionuclide content to conform to applicable standards.

The scope of this section is limited to the alternative processes for performing the initial liquid waste pretreatment step. Examples of these processes include evaporation, ion exchange, and filtration or centrifugation. Other possibilities include membrane purification processes, such as reverse osmosis and electrodialysis. These processes are not described in the detail accorded the final waste treatment processes elsewhere in this report because they are more closely related to the main plant flowsheets. The processes are often used in conjunction with in-process recycle systems that influence the main process flowsheet, and their use is often dictated by logical flowsheet development regardless of the methods used for further treatment or storage of the concentrated waste. More detailed information on these pretreatment options, background and current status of technologies, and process or facility alternatives is contained in Reference 1.

The concentrated waste streams produced by these processes are subject to further treatment discussed in other sections of this report. Any dilute waste streams that are discharged to the environment are described in this section.

4.6.1 Dilute Aqueous Waste Evaporation

Evaporation is a process used to concentrate a solution or slurry by applying heat to drive off solvent vapors. It has wide application in the nuclear industry for reducing waste volumes and the quantity of radionuclides in liquid effluents. Evaporation is usually used for radioactive wastes that require a high degree of separation between volatile and non-volatile components. It is also used for wastes that are not amenable to treatment by less costly, low-temperature operations, such as precipitation, filtration, and ion exchange.

An evaporator consists basically of a device to heat and vaporize the solution and a device to ensure efficient separation of the vapor phase from the liquid phase. In the design of evaporators used to concentrate radioactive liquids, vapor-liquid separation (deentrainment) is an important factor, since decontamination of the overhead stream is a primary objective. The decontamination factor for evaporation is commonly defined as the ratio of the radionuclide concentration in the evaporator bottoms to the corresponding radionuclide concentration in the overhead vapor. These decontamination factors normally fall within the range of 10^4 to 10^6 for

a single stage of evaporation and deentrainment. Evaporator type and design, the design and performance of associated liquid droplet deentrainment devices, and the volatilities of feed solution radionuclides are the most significant factors influencing the attainable decontamination factors. Radioactive iodine, ruthenium, and tritium are the most notable radionuclides for which evaporative decontamination can be difficult, since they are often present as volatile chemical compounds.

Several types of evaporation equipment are commercially available. The simplest type is a vessel that contains the liquid to be evaporated and is equipped with a heat transfer device, such as a steam coil or jacket, for batch operation. Other evaporators are designed for continuous rather than batch operation. In these evaporators, liquid is circulated through a heat exchanger in which condensing steam is the normal heat source. A typical natural circulation evaporator is equipped with a vertical shell-and-tube heat exchanger in which liquid circulation is induced by vapor formation within the tubes. Alternatively, a pump can be used for forced liquid circulation.

Evaporators are used extensively at proposed fuel reprocessing plants (FRPs) and to lesser extents at independent spent fuel storage basins (ISFSBS) and mixed-oxide fuel fabrication plants (MOX FFPs). At a typical FRP, each aqueous waste stream is subjected to some degree of concentration (evaporative treatment) before it is given its final waste treatment. The condensates from these concentrators are sometimes subjected to one or more additional stages of concentration to achieve additional purification before they are recycled for process use or are discharged to the environment (by another evaporator). These applications are illustrated in Figure 4.6.1, which is a schematic representation of the concentrator evaporator arrangement planned for the FRP of Exxon Nuclear Company, Inc. The arrangement planned for the FRP of Allied-General Nuclear Services (AGNS) is similar; at AGNS, however, the condensate

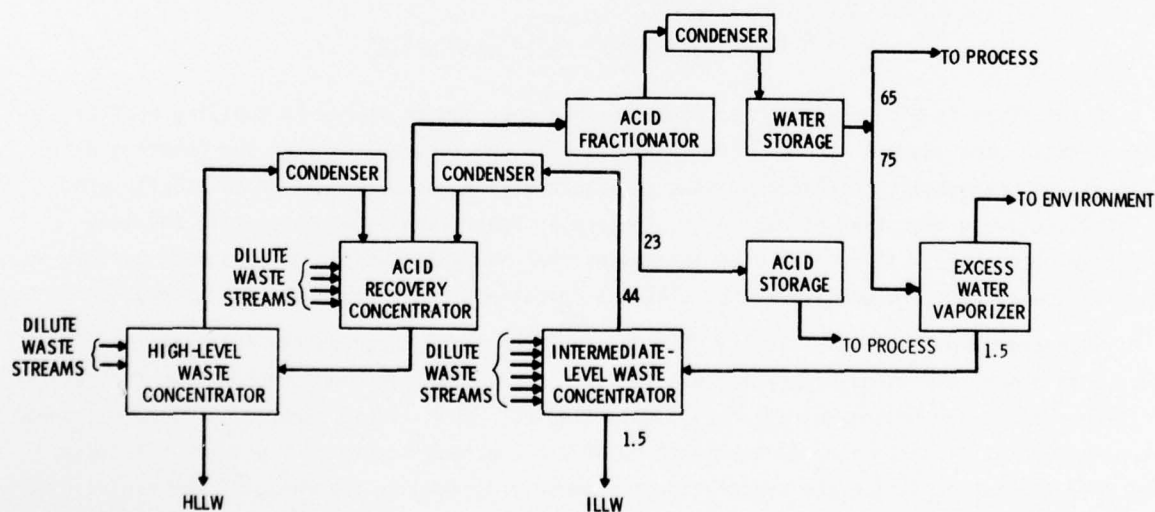


FIGURE 4.6.1. Evaporator Applications in the Fuel Reprocessing Flowsheet (Numbers beside arrows represent design flow rates in $\ell/\text{min.}$) Concentrator, Fractionator, and Vaporizer are all types of evaporator.

from the general purpose concentrator (which corresponds to the Exxon Nuclear intermediate-level waste concentrator) is routed directly to the excess water vaporizer rather than to the acid fractionator. The design flow rates of several of the streams are also included in Figure 4.6.1 to provide an indication of the required capacities.

Figure 4.6.2 shows a typical aqueous waste evaporator (the Exxon Nuclear excess water vaporizer). This thermosyphon unit is designed to provide a minimum of process liquid holdup and access to the replaceable tube-bundle heat exchanger. A stilling well is provided in parallel with the downcomer to permit the measurement of liquid level and specific gravity.

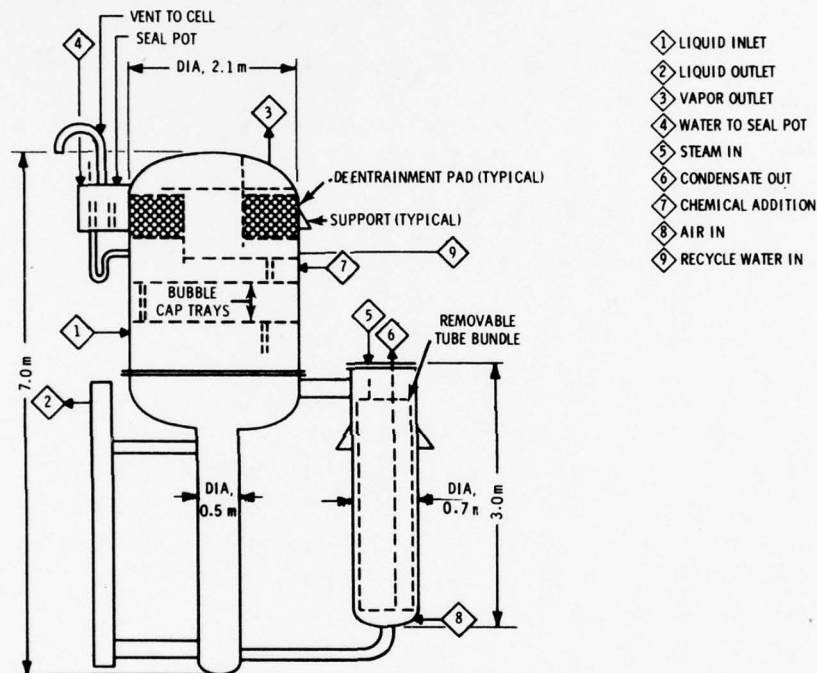


FIGURE 4.6.2. Typical Aqueous Waste Evaporator (Dimensions are those of the excess water vaporizer.)

The deentrainment section consists of two cross-flow bubble cap trays with provision for water or chemical addition. The tower is designed for a superficial vapor velocity of about 1 m per second. Two metal mesh deentrainment pads are provided in series for liquid droplet deentrainment. These pads are constructed of stainless steel, titanium, or tantalum, depending on the corrosiveness of the vapor being processed. The pads are sized for a vapor velocity of about 3 m per second.

A seal pot is provided to limit the differential pressure to which the vessel shell can be subjected.

Chemicals can be added to concentrator-evaporators to reduce the amounts of ruthenium and iodine that are vaporized. For example, sugar can be added to reduce vaporization of

4.6.4

ruthenium; caustic can be added to make the concentrator bottoms basic, which will reduce vaporization of both ruthenium and iodine; mercuric ion can be added to reduce the vaporization of iodine.

The estimated quantities of vaporized excess water and the amounts of contained radionuclides are summarized in Table 4.6.1.

TABLE 4.6.1. Activity Discharged with Vaporized Excess Water^(a)

	Released to Atmosphere, Ci/yr		
	ISFSB ^(b)	FRP ^(c)	MOX-FFP ^(d)
<u>Fission Products</u>			
³ H	--	7.1×10^5 ^(e)	--
¹²⁹ I	3.2×10^{-6}	7.0×10^{-4}	--
⁹⁰ Sr + ⁹⁰ Y	9.6×10^{-5}	2.4×10^{-8}	--
⁹⁵ Zr + ⁹⁵ Nb	1.3×10^{-6}	2.2×10^{-4}	--
¹⁰⁶ Ru + ¹⁰⁶ Rh	3.4×10^{-6}	7.6×10^{-2}	--
¹³⁴ Cs + ¹³⁴ Cs + ^{137m} Ba	9.8×10^{-3}	6.0×10^{-8}	--
¹⁴⁴ Ce + ¹⁴⁴ Pr	1.3×10^{-3}	9.6×10^{-8}	--
All other FPS	1.4×10^{-5}	2.0×10^{-8}	--
Total	1.1×10^{-2}	7.1×10^5	--
<u>Actinides</u>			
²³⁹ Pu	--	7.2×10^{-6}	1.3×10^{-9}
²⁴¹ Pu	--	3.5×10^{-3}	5.8×10^{-7}
Other Pu	--	1.2×10^{-4}	2.2×10^{-8}
²⁴² Cm + ²⁴⁴ Cm	--	3.4×10^{-9}	--
All other actinides	--	1.8×10^{-10}	9.6×10^{-8}
Total	--	3.6×10^{-3}	7.0×10^{-7}
<u>Activation Products</u>			
⁵⁵ Fe	9.0×10^{-4}	--	--
⁶⁰ Co	6.6×10^{-4}	--	--
All other APs	2.4×10^{-4}	--	--
Total	1.8×10^{-3}	--	--

a. Annual water discharges of 4×10^6 kg for ISFSB, 2×10^7 kg for FRP, and 5×10^5 kg for MOX-FFP.

b. Based on waste characterization Table 3.3.23, assuming uranium and plutonium recycle, 3000 MTHM stored, average of 3.5 years out of reactor.

c. Based on waste characterization Table 3.3.27, assuming uranium and plutonium recycle, 2000 MTHM/yr reprocessed 1.5 years out of reactor.

d. Based on waste characterization Table 3.3.37, 400 MTHM/yr fabricated 1 year after plutonium purification.

e. Assumes that all tritium except the 15% present in the hulls is released in this stream.

4.6.5

The estimated quantities and compositions of typical concentrated wastes resulting from evaporative pretreatments that are subsequently subjected to final waste treatments are listed in tables in Section 3.3. For the ISFSB, the sulfate concentrate and the miscellaneous solution concentrates are listed in Table 3.3.25; for the MOX FFP, the scrap recovery solution is listed in Table 3.3.39. For the FRP, the high-level liquid waste (HLLW) is given in Table 3.3.29; the intermediate-level liquid waste (ILLW) from the reprocessing operation and the sulfate concentrate and miscellaneous solution concentrates from the fuel receiving and storage operations are given in Table 3.3.31.

4.6.2 Dilute Aqueous Waste Ion Exchange

The relatively common technique of ion exchange has proved to be effective for removing radioactive ions from solutions that are relatively low in ionic contaminants. In these processes, the solid ion exchange material preferentially bonds with the radioactive ions to be removed rather than the non-radioactive ions present in the original ion exchange material. Ion exchange media can be obtained from naturally-occurring minerals, such as clinoptilolite and attapulgite, or manufactured from polystyrene or aluminosilicates.

Ideally, an ion exchange process can generate a virtually nonradioactive liquid effluent by trapping the radioactive feed constituents within a solid matrix (the ion exchange material). The loaded ion exchange material can either be treated by solid waste treatment methods or chemically regenerated for further use, thus producing a more concentrated liquid regeneration waste for further treatment. Since the liquid flow rate capacity of an ion exchange bed can be reduced by particulate material buildup, a filtration or centrifugation step often precedes ion exchange processing.

A typical example of an ion exchange process is the cleanup of the water used in a spent fuel storage basin. Such basins exist at each nuclear power plant and each reprocessing plant as well as at each ISFSB. A process for decontaminating the water in an ISFSB is described in Section 5.7.1. In this process the basin water is continuously removed (at a rate of about 30% to 60% of the basin volume per day), passed through a filter to remove suspended dust and insoluble materials from the fuel assemblies, circulated through a mixed-bed ion exchange column to remove soluble anionic and cationic contaminants, and returned to the basin. For the reference 3000-MTHM ISFSB, the water flow rate would be about 5700 ℓ /min (1500 gpm). Several units are required to allow some to be backflushed and regenerated while others are being used and also to provide excess capacity for rapid cleanup of severely contaminated pools. The capacity of each unit would likely be about 1000 ℓ /min (3800 gpm).

When the ion exchange material is regenerated, the regeneration solutions (sodium hydroxide and sulfuric acid) become contaminated with the radionuclides removed from the basin water; these solutions are concentrated by evaporation (Section 4.6.1) and sent to waste treatment. The estimated quantity of the concentrate is listed in Table 3.3.25 for the ISFSB, as are the estimated quantities of filter sludge and ion exchange resin replacement. The quantities resulting from similar applications at a nuclear power plant and an FRP are listed in Tables 3.3.20 and 3.3.31, respectively.

A simplified schematic diagram of this application of ion exchange is shown in Figure 4.6.3. No effluents are discharged directly to the environment from these ion exchange processes.

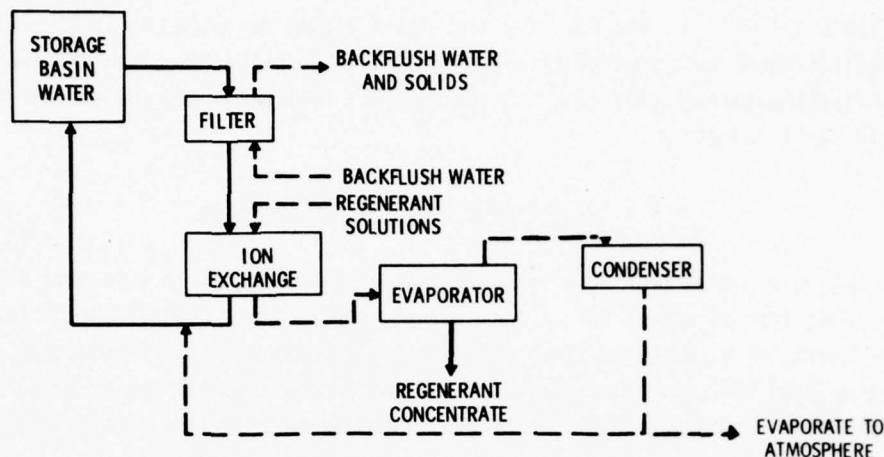


FIGURE 4.6.3. Ion Exchange Application at a Spent Fuel Storage Basin

4.6.3 Filtration and Centrifugation

Filtration or centrifugation can be used at virtually any point in a sequence of liquid waste treatment operations to remove insoluble particulate material. This removal is often the initial step in situations where undissolved matter would have a deleterious effect upon downstream treatment processes or equipment, such as in the ion exchange case discussed in the preceding section. In some specific applications, filtration or centrifugation may be the only step necessary prior to reuse or discharge of the filtered liquid. In other applications, with liquid wastes containing contaminants that can be readily flocculated or precipitated by chemical additions, particle removal is a secondary step in the sequence; in fact, more than one stage of precipitation and filtration may be needed to obtain the desired degree of decontamination. Filtration or centrifugation can also be used as a final "polishing" step for liquid wastes that have retained small amounts of suspended solids throughout other treatment processes.

Flocculation and precipitation processes basically involve adding chemicals to the liquid waste to produce chemical reactions that will incorporate the radioactive contaminants into insoluble substances. The insoluble substances are then separated from the liquid phase by filtration or centrifugation (or by settling). Precipitation processes are generally rapid and result in an easily separable solid phase. On the other hand, flocculation processes require more controlled conditions (degree of agitation, residence time, temperature, etc.) to promote the formation of finely divided precipitating solids and the agglomeration of these solids into progressively larger floc. This floc material can also carry colloidal materials out of solution.

4.6.7

Filtration is a process for removing solids from a liquid waste stream by passing the liquid through porous media. The porous media remove coarse solids, suspended solids, and, depending on the type of filtration medium, some colloidal solids. The recovered solids may be included with the filtration medium as a solid waste or removed from the filter (e.g., by backwashing) for further treatment.

The porous media used for filtration can be shaped into many forms using different kinds of materials. Filters that use granular media, often in layers with varying degrees of porosity, are the oldest type for water treatment applications. Disposable or cartridge filters contain replaceable elements that are treated as solid waste when they become clogged. The disposable elements are usually made of cotton fabrics, pressed paper, matted fibers, or porcelain materials. Several types of metallic filter elements, some of which are more cleanable than others, are available. These metallic elements are constructed of woven wire, sintered metal, or chemically etched disks. Precoat filters use elements designed to retain a disposable powdery or granular precoat material, commonly diatomaceous earth, which serves as the actual filtration medium.

Centrifugation is a process in which centrifugal force is used to separate substances of different densities, such as suspended materials and clear liquids. Centrifuges are mechanically-driven devices that have a wide variety of possible designs and operating characteristics. Solids-bearing fluids are fed into a rotating section that imparts rotational motion to the suspension. Residence time in this section is dependent on feed rate and section volume. As higher density materials are accelerated toward the periphery while traversing the rotating section, suspended particles are separated from the liquid phase. Separate exit points are provided for discharge of solids and clarified liquids.

A hydroclone is a simple device with no moving parts that removes relatively dense suspended solids from a liquid stream. In this device, fluid pressure energy creates rotational fluid motion in a conically shaped vessel. This motion produces centrifugal action and permits separation of solid materials from the fluid. The bulk of the fluid is removed through a top outlet while separated solids are discharged through an axially located bottom outlet.

Liquid radioactive wastes from nuclear power plants are treated with a typical filtration process. This description could also apply to centrifugation, since centrifuges are sometimes used in place of filters in this same application. However, filters are used more often because of cost and maintenance factors.

Figure 4.6.4 shows a sketch of a typical filtration process. Liquid wastes are segregated according to anticipated levels of radioactivity and are collected in three concentric tanks. This tank design allows the low-level radioactive wastes in the outer tank to provide shielding from the progressively more radioactive wastes in the inner two vessels. Sources of waste input to the inner tank include hot laboratories, hot samples, containment, and primary equipment drains. The intermediate tank receives drains from the refueling area, radioactive waste equipment area, sample sinks, and demineralizer regeneration. Low-level radioactive drainage wastes from laundry and shower facilities, cold laboratories, and auxiliary equipment are routed to the outer tank.

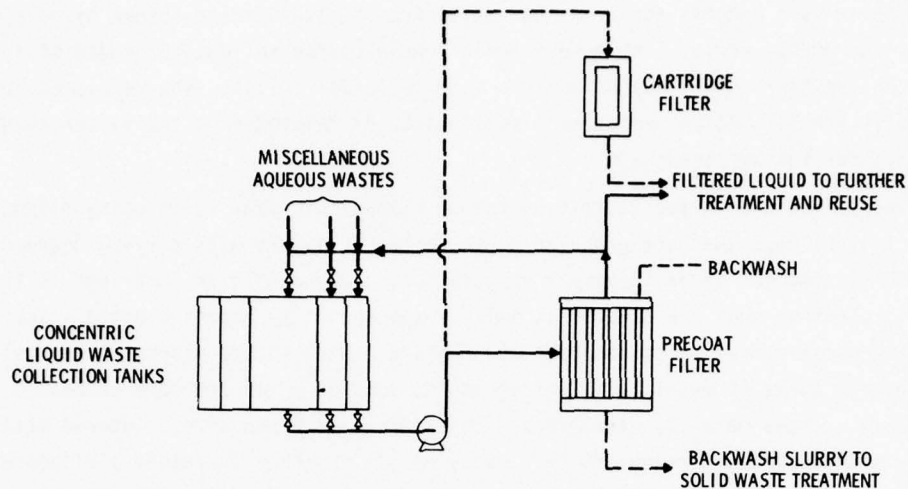


FIGURE 4.6.4. Nuclear Power Plant Liquid Waste Filtration System

A diatomaceous earth precoat filter is used in the treatment of these liquid wastes. This filter consists of precoatable porous "wedgewire" tube elements that have an effective filter area of about 1.2 m^2 (13 ft^2) and are designed for a flow rate of 280 l/min (75 gpm). The filter precoat is about 1.4 kg (3 lb) of diatomaceous earth. The normal maximum pressure differential across the filter will be 35 psi ; the vessel design pressure is 150 psig at 93°C . The filter will remove any suspended material 2μ or larger. A decontamination factor of at least 10 per filter cycle is expected; however, actual decontamination factors will be much higher since liquid wastes are recycled through the filter several times.

To prepare for operation, a diatomaceous earth slurry is pumped into the filter for precoat loading. Liquid wastes from one of the three feed tanks are pumped through the filter at about 280 l/min (75 gpm). About 15% of the filtered liquid is withdrawn for further treatment and reuse, and the remaining 85% is recirculated to the tank of origin. When the filter is loaded with collected solids to a differential pressure of 35 psi (about once per week), the unit is backwashed, rinsed, and supplied with fresh precoat material. A cartridge filter is installed for use in place of the precoat filter while the precoat filter is being backwashed.

Most of the filtered liquid is generally reused as process water, and the excess is discharged to the environment. Prior to reuse or discharge, further purification is performed as required. The collected particulate material and spent diatomaceous earth precoat are routed to the solid radioactive waste system for further treatment. Estimated quantities of these materials are contained in Table 3.3.20. Quantities resulting from filtration operations at the ISFSB and the FRP are given in Tables 3.3.25 and 3.3.31, respectively.

4.6.4 Membrane Processes

In membrane processes, the membranes inhibit the passage of molecular or ionic species so that, by appropriate multistage arrangements, it is possible to achieve considerable separation of dissolved solutes from water. Such processes, however, are not as well developed for radioactive waste treatment applications as are the processes described previously.

Reverse osmosis and electrodialysis are membrane processes that could potentially be used to treat dilute aqueous waste streams; however, additional developmental work and more favorable economic incentives are needed prior to extensive application. Both processes separate soluble constituents from the liquid by passing it through membranes. In the case of reverse osmosis, an aqueous solution is pressurized (above the osmotic pressure) in contact with a semipermeable membrane; purified solution passes through the membrane, and the remaining solution contains the concentrated solutes. In the case of electrodialysis, solute ions pass through membranes placed between electrodes immersed in the solution while the liquid flows through a compartmented cell containing alternate cationic and anionic membrane compartment walls. The liquids leaving alternate compartments thus contain depleted and increased concentrations of the solutes.

Either process could be used as a sole pretreatment method or in combination with other pretreatment processes, such as ion exchange or evaporation.

REFERENCES FOR SECTION 4.6

1. Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle, ERDA 76-43, Energy Research and Development Administration, Washington, DC, Vol. 2, Section 10, May 1976.

4.7 IMMOBILIZATION OF WET AND SOLID WASTES

4.7 IMMOBILIZATION OF WET AND SOLID WASTES

The operation of any facility in the postfission nuclear fuel cycle results in the generation of radioactive concentrated liquids, wet wastes, and particulate solids. Prior to shipping and disposing of these wastes, their immobilization to a monolithic form is required. This immobilization step may be accomplished by a variety of methods, each with its own unique process characteristics.

Three immobilization technologies already well demonstrated in operating nuclear facilities are the bitumenization system, the cementation system, and the urea-formaldehyde system. Each system is commercially available and in use in existing facilities. A variety of lesser-developed systems are proposed for radioactive waste immobilization. Included are various absorbents and polymeric solidification processes. Except for absorbents, these systems are not yet in commercial use.

As the need to build a radioactive waste immobilization facility is demonstrated, a plant operator will have to choose from among several operational alternatives. With available concepts, a plant may be operated either remotely or with localized shielding to minimize operator radiation exposure. Either contact or remote maintenance may be used. The operator may choose to reduce the volume of his immobilized waste form, thereby increasing radiation levels from the waste. He may decide to evaporate free water from the radioactive waste, thus reducing the volume; however, this procedure necessitates the installation of a steam recovery/cleaning system and possibly a system for contaminated water recycle and/or disposal. The advantages and disadvantages associated with the radioactive waste immobilization system alternatives must be evaluated while keeping sight of the design objective. That is, a nuclear facility must produce an immobilized radioactive waste form that will protect the environment, meet all pertinent Federal regulations, and be of lowest possible cost.

4.7.1 Bitumen Immobilization at a Fuel Reprocessing Plant

The use of bitumen to immobilize radioactive wastes has been well demonstrated largely through extensive operating experience. The development of the bitumenization processes has proceeded mainly in Europe. Basically, the system, whether batch or continuous, operates by mixing the untreated radioactive waste with bitumen at temperatures above 100°C (212°F). Greater than 99.5% of the water in the radioactive waste is evaporated. The resulting bitumen and radioactive waste mixture is placed in a shipping container and allowed to cool. The final waste form has a reduced volume relative to that of cement but has an increased surface radiation dose rate.

4.7.1.1 Bitumenization Process Alternatives at the Fuel Reprocessing Plant

Both batch and continuous bitumenization units have been developed for the immobilization of radioactive wastes. A batch stirred-evaporator process has been developed in Europe, a continuous turbulent film evaporator process has been developed by several interests worldwide, and a screw extruder process has been developed in Europe at Marcoule, France, and Karlsruhe, Germany. A brief description of each process may be found in ERDA 76-43.⁽¹⁾

4.7.2

The reference bitumenization process selected for this study is the continuous screw extruder process, which is commercially available from the Werner and Pfleiderer Corporation (WPC).⁽²⁾ This selection is based on the following considerations:

1. The screw extruder bitumenization process operates at lower temperatures and with shorter residence times than the batch process, thus minimizing off-gas problems.
2. The reference process uses demonstrated technology. The system has not only been used to immobilize radioactive waste but has been used with good reliability in the plastics industry, as well as others.
3. The process is commercially available in the United States.

4.7.1.2 Design Basis for the Bitumen Immobilization Facility at the Fuel Reprocessing Plant

A remotely operated bitumen immobilization facility (BIF) is proposed for the reference FRP for radioactive waste immobilization. The conceptualized shielded facility is located adjacent to the separations facility. It is designed to receive and immobilize intermediate-level wastes and low-activity wastes, both of the transuranic (TRU) and nontransuranic categories (non-TRU). Administrative control is used to segregate products according to the TRU content. The BIF is required to process waste with up to 1000 Ci per m³ of mixed fission products and/or transuranics. In addition, it must be capable of processing at least 300 m³ of FRP wastes per year.

4.7.1.3 Process for the Bitumen Immobilization Facility at the Fuel Reprocessing Plant

Bitumen immobilization is a one-step volume reduction and solidification process. It uses a screw extruder-evaporator to remove free water, mix radioactive wastes with bitumen, and homogeneously disperse the wastes in a bitumen matrix. This waste solidification process is used to convert all FRP particulate and wet wastes into a monolithic solid on a continuous processing basis. FRP particulate and wet wastes and their sources are listed in Table 4.7.1 and illustrated in Figure 4.7.1.

TABLE 4.7.1. Fuel Reprocessing Plant Particulate and Wet Wastes

Source	Description
Fuel receiving and storage facility	Mostly non-TRU, intermediate-level solutions and slurries of ion exchange resins, filter aids, and concentrated solutions
Separations facility	Primarily intermediate-level TRU concentrated solutions and slurries
PuO ₂ conversion facility	Low-level TRU solutions and slurries (volumes would be combined with separations facility wastes)
UF ₆ conversion facility	Low-level; little or no TRU content; low water content; composed of oxides, hydroxides, and fluorides
Waste treatment facilities	Secondary wastes arising from waste treatment operations, including incinerator ashes, off-gas scrub solutions, and decontamination solutions

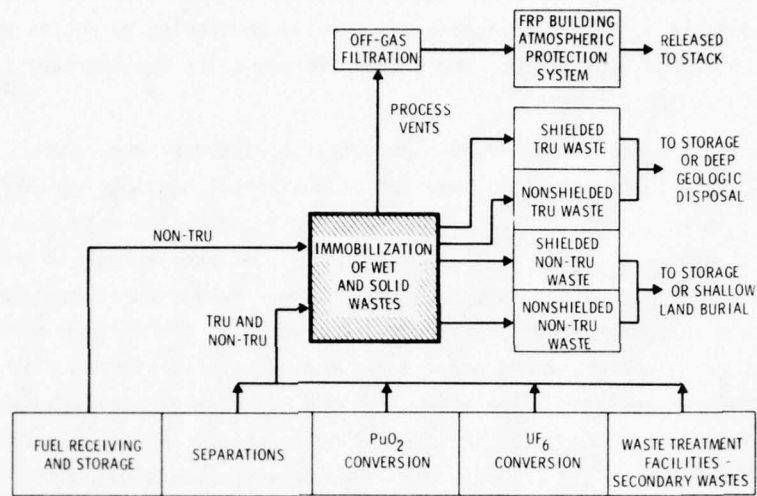


FIGURE 4.7.1. System Interactions for the Fuel Reprocessing Plant Waste Solidification Process

It is also used to encapsulate spent cartridge filters and similar small solid wastes that can be inserted into the waste containers prior to filling them with bitumenized wastes.

A simplified system flowsheet for the reference process is shown in Figure 4.7.2. As shown, the major components of the process are feed preparation; product mixing; water evaporation; and product packaging, inspection, survey, and interim storage. The entire process is controlled remotely.

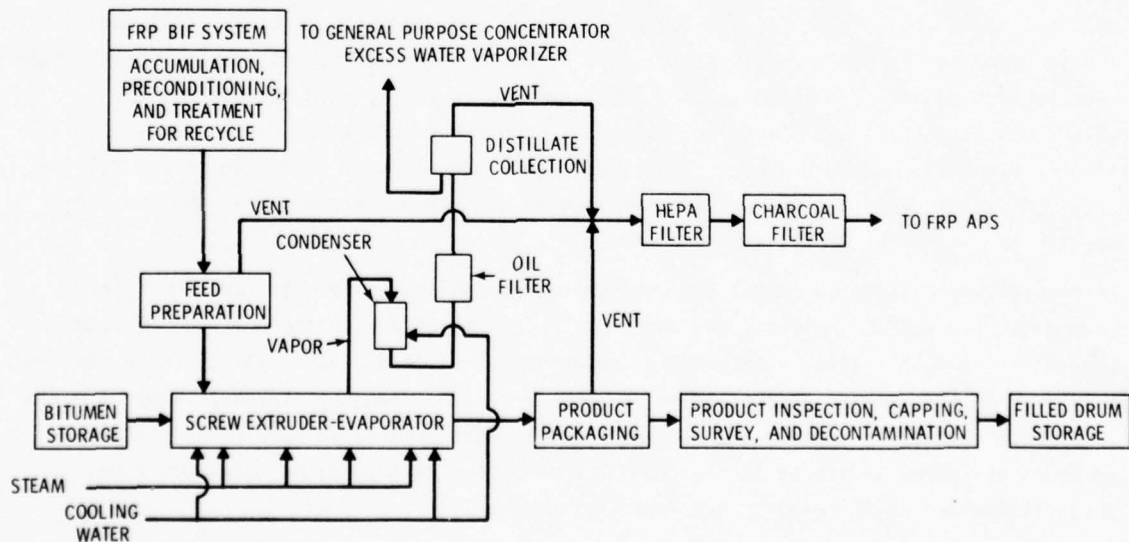


FIGURE 4.7.2. System Flowsheet for the Fuel Reprocessing Plant Bitumen Immobilization Facility

4.7.4

Preconditioned liquid and slurry radioactive wastes are pumped to the extruder from a feed tank on a continuous basis. Preconditioning may involve dewatering of resins and sludges and a pH adjustment in the range of 7 to 10. The bitumen is pumped to the extruder from a heated storage tank maintained at 120°C (248°F).

The heart of the bitumen immobilization unit is the extruder-evaporator. It consists of twin co-rotating screws that operate in a series of horizontal housings or barrels that are divided into zones in which the temperature is separately controlled with high pressure steam and cooling water. The waste and preheated bitumen are continuously pumped into the inlet barrel, where the screws mix, knead, and transport the waste-bitumen mixture through the barrel. The mixing and kneading action transforms the mixture to a thin film that aids in the evaporation of the entrained water and permits the screws to self-wipe each other along the length of the extruder-evaporator. The steam from the evaporated entrained water is vented through steam domes and then condensed in integral condensers. The distillate is then passed through oil filters to remove any organics distilled from the waste-bitumen mixture and recycled to the FRP general purpose concentrator and/or to the excess water vaporizer. The distillate is relatively pure; decontamination factors (feed to distillate) on the order of 6000 have been measured for nonvolatiles. The waste-bitumen product is discharged at the end of the screw extruder into drums. Average residence time in the extruder is from one to a few minutes. The temperature in the extruder varies from 70°C (158°F) in the first barrel to 175°C (347°F) in the last barrel.

The waste-bitumen product is discharged from the extruder into drums positioned on a transfer cart. An overhead crane is used to place empty drums on the cart and transfer the filled ones. Department of Transportation (DOT) Specification 17C, 55-gal steel drums are used. Drum filling is observed by the operator through shielded windows and/or a closed-circuit television system. The operator can monitor and control all aspects of filling from the system control panel. The filling operation can be programmed to partially fill each drum in sequence to improve the fill efficiency, allowing some cooling and associated shrinkage to occur between additions. Three filling sequences are generally used to increase the effective capacity of a drum. Cartridge filters, including oil filters used to treat the distillate, are encapsulated by remote insertion into a barrel prior to the described filling sequence. Activity levels in the wastes processed in the FRP BIF are shown in Table 4.7.2; volumes for the untreated wastes are also noted.

A remotely-operated drum capper and monitoring station is provided to cap the filled drums, monitor the radiation level, and obtain a "swipe" to determine the presence of external contamination. Should a drum be externally contaminated, it is placed in the cleaning station. Steam is used as the solvent when cleaning is necessary. The cleaning effluent (about 1 gal or $4 \times 10^{-3} \text{ m}^3$ per cycle) is drained and returned to the plant general purpose concentrator. Filled drums are normally stored in the cooling chamber for 24 hr. After the product has cooled sufficiently, it is moved to the drum storage area.

TABLE 4.7.2. Activity in Untreated Wastes for Fuel Reprocessing Plant Wet TRU Waste Immobilization Facilities(a)

Radionuclide	Ci/yr		Total
	Primary Wastes (b)	Secondary Wastes (c)	
Fission products			
³ H	840	25	865
¹²⁹ I	0.21	0.007	0.21
⁹⁰ Sr + ⁹⁰ Y	2,400	600	3,000
⁹⁵ Zr + ⁹⁵ Nb	22,000	240	22,240
¹⁰⁶ Ru + ¹⁰⁶ Rh	760,000	8,400	768,400
¹³⁴ Cs + ¹³⁷ Cs + ^{137m} Ba	6,000	1,500	7,500
¹⁴⁴ Ce + ¹⁴⁴ Pr	9,600	2,400	12,000
All Other Fission Products	2,000	500	2,500
TOTAL	803,000	13,700	817,000
Actinides			
²³⁹ Pu	720	500	1,220
²⁴¹ Pu	350,000	240,000	590,000
Other Pu	12,000	8,300	20,300
²⁴² Cm + ²⁴⁴ Cm	340	100	440
All Other Actinides	18	5	23
TOTAL	363,000	249,000	612,000
Activation products			
⁵⁵ Fe	0	830	830
⁶⁰ Co	0	830	830
⁹⁵ Zr + ⁹⁵ Nb	0	60	60
All Other Activation Products	0	800	800
TOTAL	0	2,520	2,520

a. Based on waste characterization Tables 3.3.31 and 3.3.32 and secondary waste Table 3.5.1, assuming uranium and plutonium recycle, 2000 MTHM/yr reprocessed 1.5 years out of reactor.

b. Volume = 298 m³/yr.

c. Volume = 574 m³/yr.

A process flow diagram for processing primary wastes through the FRP BIF is shown in Figure 4.7.3. Material balances for primary and secondary TRU waste processing are shown in Table 4.7.3. The treated wastes are described in Table 4.7.4. One characteristic of the immobilized waste product of great importance is the leach rate. Leach rates of bitumen immobilized waste product have been measured at 10^{-4} to 10^{-7} g/cm² - day and 10^{-7} to 10^{-8} g/cm² - day for alkali and alkaline earths and for actinides and rare earths, respectively. As shown on Table 4.7.4, five product streams from the FRP BIF exist which occur as a result of the processing campaign mode-of-operation. In the order as listed in Table 4.7.4, 42 drums/yr are produced with a dose rate less than 0.2 R/hr. These are the main plant silica gel wastes

(see Table 3.3.31). They are processed separately because they are dry and may be processed quickly (relative to liquid wastes), because they are received batchwise from a single source, and because they have a very low surface dose rate as an immobilized product. In the dose rate category of 0.2 to 1.0 R/hr, 659 drums/yr are produced. These are derived from the UF_6 plant fluorinator and contain the fluorinator beds and fines. They are processed in campaigns because they are dry and may be processed quickly and because their surface dose rates are relatively low. The ILLW and miscellaneous secondary solutions are processed together and result in 685 drums with average surface dose rates of 1,370 R/hr. They are processed together to isolate the primary sources of radioactive material. The incinerator ash is processed as a single waste stream and results in 298 drums/yr with an average surface dose rate of 50 R/hr. The rationale for processing the stream separately is that, like the silica gel wastes, they are dry and may be processed quickly and because they are a major source of radioactivity. Finally, the incinerator scrubber solution is processed separately and results in 844 drums/yr with an average dose rate of 0.24 R/hr. It is processed separately because of the low dose rate of the product.

As stated previously, the FRP BIF is designed to process all TRU and some non-TRU FRP wastes. The processing of all TRU wastes will require approximately 5190 hr/yr. For non-TRU waste processing, 2350 hr/yr are required. Thus, the projected annual operating hours for the FRP BIF will be 7540, which yields an operating capacity factor of 0.85. For a contact maintenance facility this may be an optimistic estimate of operating capacity. However, the Werner and Pfleiderer Corporation has demonstrated higher operating capacities in hot facilities. If this capacity requirement were judged too optimistic, two direct alternatives would be available. First, an additional extruder could be installed. Second, non-TRU wastes could be processed in alternate facilities. A variety of other alternatives are available.

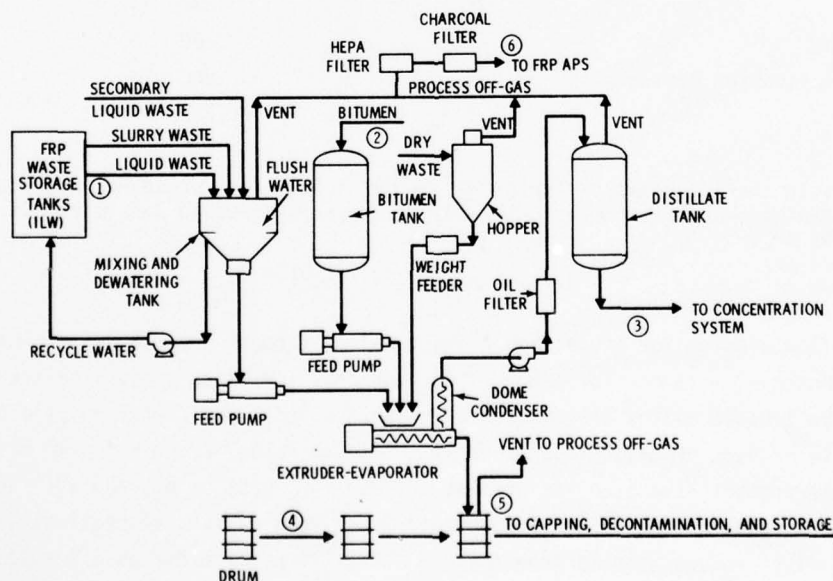


FIGURE 4.7.3. Process Flow Diagram for the Fuel Reprocessing Plant Bitumen Immobilization Facility

TABLE 4.7.3. Material Balance for the Treatment of Transuranic Waste at the Fuel Reprocessing Plant
Bitumen Immobilization Facility

Stream Number	Stream Material Description	Volume m ³ /yr	Density kg/m ³	Mass kg/yr	Temperature °C	Number of Drums/yr	Plutonium g/yr	Uranium kg/yr	Fission Product 95Zr + 95Nb	106Ru + 106Rh	129I	Radioactivity (a) AT Other Fission Products	Pu	U	AT Other Actinides	AT Activation Products
PRIMARY WASTE																
1	Primary Waste Feed															
	Fluorinator Bed Residue (b)	8	1,500	12,000	Ambient	76	5	12	1 x 10 ⁻⁵	1 x 10 ⁻⁴	0	0	0.569	0.390	0.817	0
	Fluorinator Fines (b)	60	1,500	90,000	Ambient	583	24	2,890	1 x 10 ⁻⁴	0.001	0	0	1 x 10 ⁻⁴	0.002	0	0
	1LLW (c)	220	1,250	275,000	Ambient	607	24,300	1,940	0.99	0.99	0.967	0.80	6 x 10 ⁻⁴	0.585	0	0
	Silica Gel (c)	10	800	8,000	Ambient	42	2.4	0	1 x 10 ⁻⁴	0	0	0	6 x 10 ⁻⁵	0	0	0
2	Bitumen	181	1,050	190,000	120	0	0	0	0	0	0	0	0	0	0	0
3	Distillate	200	1,000	200,000	40	0	4.1	0.8	2 x 10 ⁻⁴	2 x 10 ⁻⁴	2 x 10 ⁻⁴	1 x 10 ⁻⁴	9 x 10 ⁻⁵	2 x 10 ⁻⁴	1 x 10 ⁻⁴	0
4	Empty Drums	284	115	32,700	Ambient	1,308	0	0	0	0	0	0	0	0	0	0
5	Filled Drums	284	1,460	414,000	Ambient	1,308	24,300	4,840	0.990	0.991	0.967	0.80	0.570	0.977	0.817	0
6	Process Vent (e)				Ambient		2 x 10 ⁻⁵	5 x 10 ⁻⁶	1 x 10 ⁻⁹	1 x 10 ⁻⁹	1 x 10 ⁻⁴	8 x 10 ⁻¹⁰	6 x 10 ⁻¹⁰	1 x 10 ⁻⁹	8 x 10 ⁻¹⁰	0
SECONDARY WASTES - MISCELLANEOUS SOLUTIONS																
1	Miscellaneous Solutions (d)	34	1,200	41,000	Ambient	78	2,200	97	0.001	0.001	6 x 10 ⁻⁴	0.080	0.054	0.019	6 x 10 ⁻⁴	0.99
2	Bitumen	10	1,050	10,500	120	0	0	0	0	0	0	0	0	0	0	0
3	Distillate	30	1,000	30,000	40	0	0.37	1.6 x 10 ⁻²	2 x 10 ⁻⁷	2 x 10 ⁻⁷	1 x 10 ⁻⁷	1 x 10 ⁻⁵	9 x 10 ⁻⁶	3 x 10 ⁻⁶	1 x 10 ⁻⁷	2 x 10 ⁻⁴
4	Empty Drums	17	115	1,950	Ambient	78	0	0	0	0	0	0	0	0	0	0
5	Filled Drums	17	1,360	23,200	Ambient	78	2,200	97	0.001	0.001	6 x 10 ⁻⁴	0.080	0.054	0.019	6 x 10 ⁻⁴	0.99
6	Process Vent (e)				Ambient		2 x 10 ⁻⁶	1 x 10 ⁻⁷	1 x 10 ⁻¹²	1 x 10 ⁻¹²	6 x 10 ⁻⁸	8 x 10 ⁻¹¹	5 x 10 ⁻¹¹	2 x 10 ⁻¹¹	6 x 10 ⁻¹³	1 x 10 ⁻⁹
SECONDARY WASTES - INCINERATOR ASHES																
1	Incinerator Ash (d)	170	230	39,100	Ambient	298	14,000	19	0.010	0.010	6 x 10 ⁻⁴	0.127	0.361	0.004	0.164	0.010
2	Bitumen	37	1,050	39,100	120	0	0	0	0	0	0	0	0	0	0	0
3	Distillate	0	1,000	0	40	0	0	0	0	0	0	0	0	0	0	0
4	Empty Drums	65	115	7,450	Ambient	298	0	0	0	0	0	0	0	0	0	0
5	Filled Drums	65	1,320	85,700	Ambient	298	14,000	19	0.010	0.010	6 x 10 ⁻⁴	0.127	0.361	0.004	0.164	0.010
6	Process Vent (e)				Ambient		1 x 10 ⁻⁵	2 x 10 ⁻⁸	1 x 10 ⁻¹¹	1 x 10 ⁻¹¹	6 x 10 ⁻⁸	1 x 10 ⁻¹⁰	4 x 10 ⁻¹⁰	4 x 10 ⁻¹²	2 x 10 ⁻¹⁰	1 x 10 ⁻¹¹
SECONDARY WASTES - INCINERATOR SCRUBBER SOLUTION																
1	Incinerator Scrubber Solution (d)	370	1,200	444,000	Ambient	844	600	0.48	2 x 10 ⁻⁴	2 x 10 ⁻⁴	0.032	0.002	0.016	1 x 10 ⁻⁴	0.019	1 x 10 ⁻⁵
2	Bitumen	106	1,050	111,000	120	0	0	0	0	0	0	0	0	0	0	0
3	Distillate	333	1,000	333,000	40	0	0.1	8 x 10 ⁻⁵	3 x 10 ⁻⁸	3 x 10 ⁻⁸	5 x 10 ⁻⁶	3 x 10 ⁻⁷	3 x 10 ⁻⁶	2 x 10 ⁻²	3 x 10 ⁻⁶	2 x 10 ⁻⁹
4	Empty Drums	184	115	21,100	Ambient	844	0	0	0	0	0	0	0	0	0	0
5	Filled Drums	184	1,320	243,000	Ambient	844	600	0.48	2 x 10 ⁻⁴	2 x 10 ⁻⁴	0.032	0.002	0.016	1 x 10 ⁻⁴	0.019	1 x 10 ⁻⁵
6	Process Vent (e)				Ambient		6 x 10 ⁻⁷	5 x 10 ⁻¹⁰	2 x 10 ⁻¹³	2 x 10 ⁻¹³	3 x 10 ⁻¹¹	2 x 10 ⁻¹²	2 x 10 ⁻¹¹	1 x 10 ⁻¹³	2 x 10 ⁻¹¹	1 x 10 ⁻¹⁴

a. Fraction of input radioactivity (Table 4.7.2). The specific isotopes shown are the major contributors to the product radiation dose rate. Iodine is listed for general information.

b. Characterized in Primary Waste Table 3.3.32.

c. Characterized in Primary Waste Table 3.3.31.

d. Characterized in Secondary Waste Table 3.3.31.

e. 820 m³/hr of air.

4.7.3

TABLE 4.7.4. Treated Waste From FRP Bitumen Immobilization

Waste Type and Surface Dose Rate Class	Volume ^(a) m ³ /yr	Density kg/m ³	Volume Ratio Treated/Untreated	Drums Per Year	Radioactivity Factors ^(b)		
					Fission Products	Actinides	Activation Products
Bitumenized Wet and Particulate Wastes							
<0.2 R/hr (0.13 R/hr)	8.8	1,460	0.88	42	Zr, Nb = 1×10^{-4} Other = 0	Pu = 6×10^{-5} Other = 0	All = 0
0.2-1.0 R/hr (0.35 R/hr)	138	1,460	2.0	659	Zr, Nb = 1×10^{-4} Ru, Rh = 0.001 Other = 0	U = 0.575 Pu = 7×10^{-4} Other = 0	All = 0
>10 R/hr (1,370 R/hr)	144	1,460	0.57	685	³ H = 0.005 I = 0.967 Zr, Nb = 0.99 Ru, Rh = 0.989 Other = 0.871	U = 0.421 Pu = 0.623 Other = 0.818	All = 0.99
Bitumenized Incinerator Ash							
>10 R/hr (50 R/hr)	63	1,320		298	³ H = 0 I = 6×10^{-4} Zr, Nb = 0.010 Ru, Rh = 0.010 Other = 0.127	U = 0.004 Pu = 0.361 Other = 0.164	All = 0.010
Bitumenized Incinerator Scrubber Solution							
0.2-1 R/hr (0.24 R/hr)	180	1,320		844	³ H = 3×10^{-6} I = 0.032 Zr, Nb, Ru, Rh = 2×10^{-4} Other = 0.002	U = 1×10^{-4} Pu = 0.016 Other = 0.019	All = 1×10^{-5}

a. Treated volume based on container volume.
b. Fraction of facility input (Table 4.7.2).

4.7.1.4 Description of the Bitumen Immobilization Facility at the Fuel Reprocessing Plant

The FRP BIF is assumed to be an integral part of the FRP and will be a Category I structure. Figure 4.7.4 shows the approximate location of the BIF. A conceptual layout of the immobilization, storage, and loadout facilities is shown in Figures 4.7.5, 4.7.6, and 4.7.7. The system is designed so that major components are located in separate cubicles or rooms to reduce radiation exposure during maintenance.

The total floor space of the FRP facility is about 550 m² (6000 ft²) — about 180 m² (1900 ft²) allotted to the solidification facility; 120 m² (1260 ft²) to shielded drum storage (sufficient for 3 months of operation); and the remainder to miscellaneous storage, truck loadout, and crane maintenance. The interior height of the building is about 7.5 m (24.5 ft).

Major Process Equipment. The FRP BIF contains the following eight major system components:

- waste feed system
- bitumen feed system
- screw extruder-evaporator
- filling and capping stations
- inspection and decontamination stations
- container transfer cart
- bridge cranes
- control module.

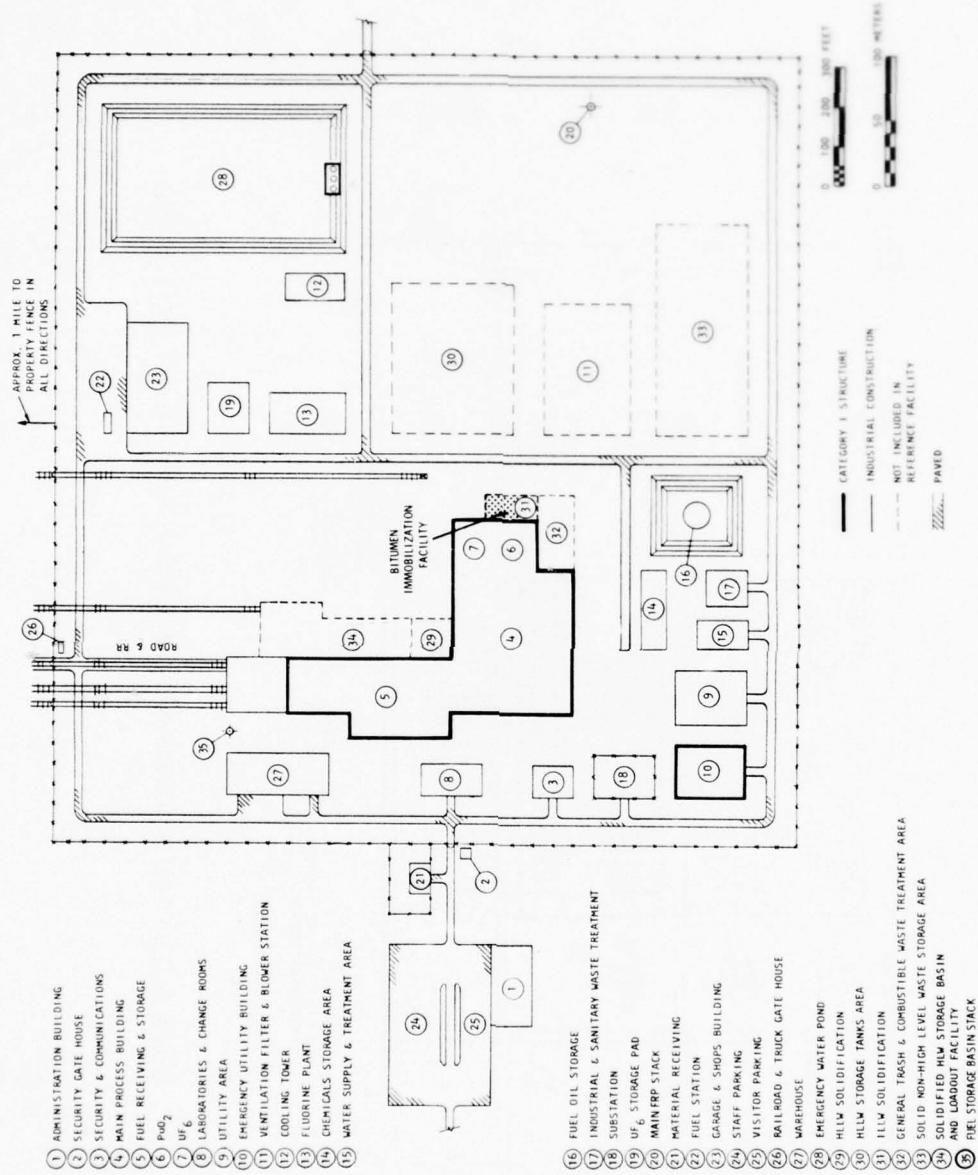


FIGURE 4.7.4. Approximate Location of the Bitumen Immobilization Facility at the Fuel Reprocessing Plant

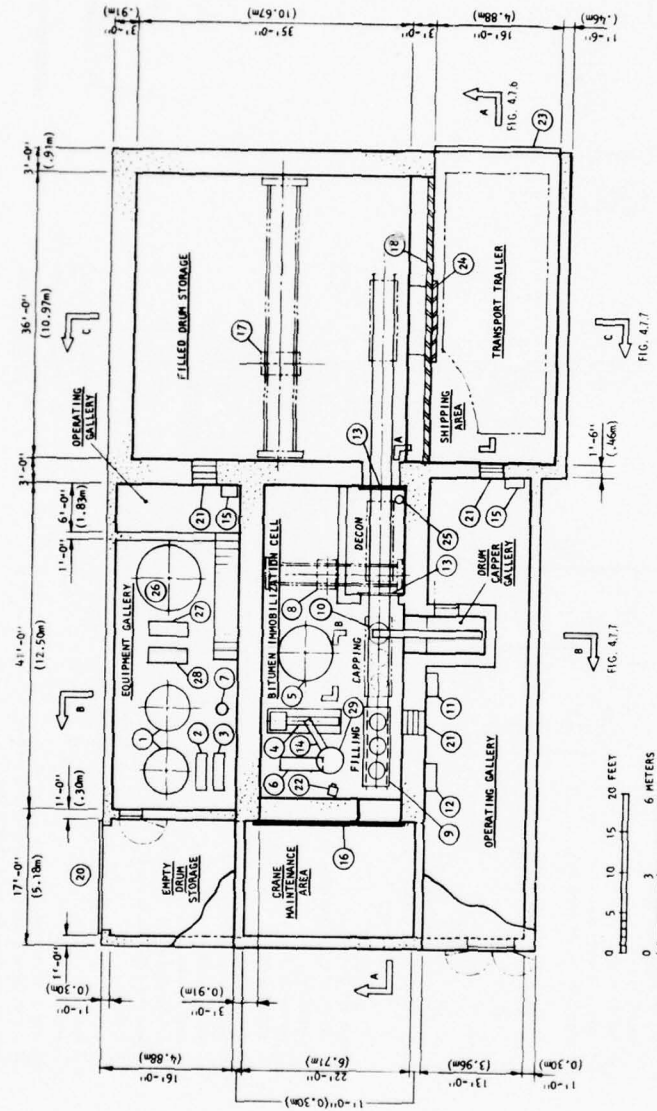


FIGURE 4.7.5. Fuel Reprocessing Plant Bitumen Immobilization Facility Plan

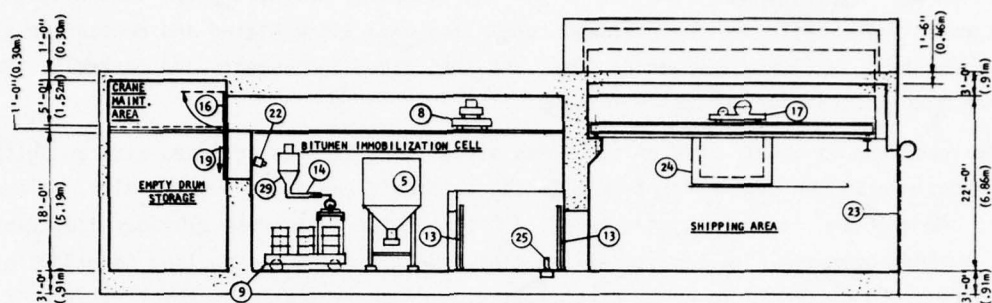


FIGURE 4.7.6. Fuel Reprocessing Plant Bitumen Immobilization Facility Plan, Section A-A (Circled numbers refer to the key in Figure 4.7.7.)

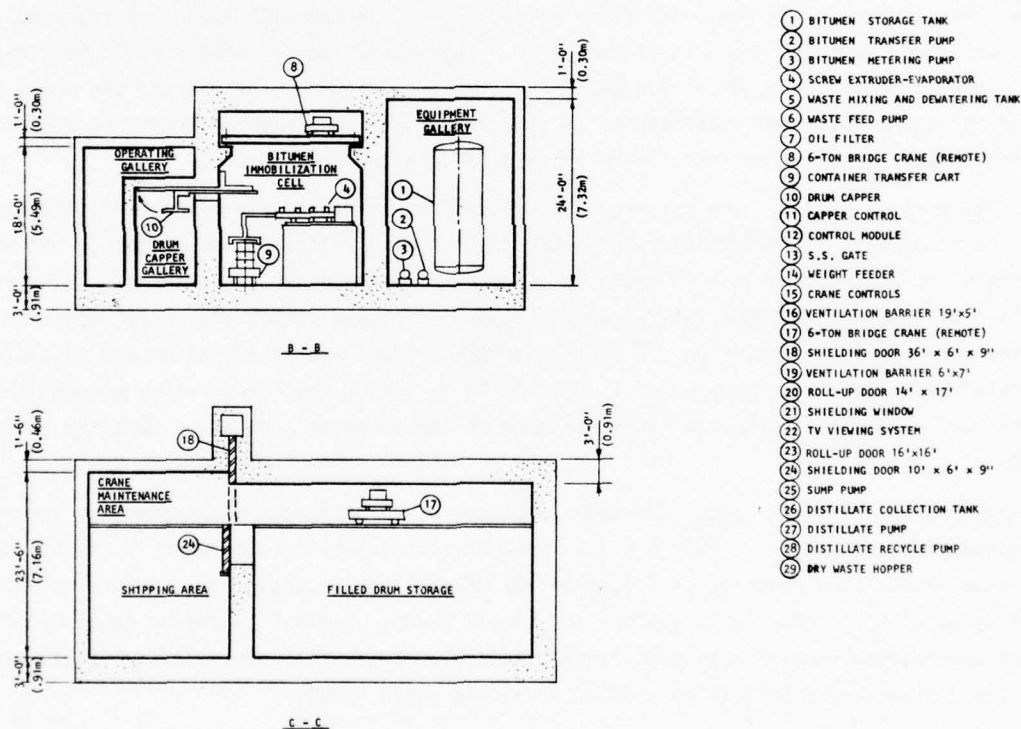


FIGURE 4.7.7. Fuel Reprocessing Plant Bitumen Immobilization Facility Plan, Sections B-B and C-C

Waste Feed System. TRU and non-TRU waste collection and evaporation systems are assumed to exist as part of the primary FRP facility. Segregated by administrative controls, the two waste streams enter the waste feed system, consisting of a waste mixing and dewatering tank, a waste feed pump, a slurry dewatering pump, and associated instruments and controls. Gear pumps are used to transfer the waste streams.

The feed tank is constructed of stainless steel. The tank is equipped with an agitator, a spray nozzle washdown system for tank cleaning, a liquid and slurry waste inlet, a level monitor, and vent and overflow connections. A high liquid-level probe provides redundant protection against overfilling the waste mixing tank. Heat tracing is supplied to maintain the temperature at 60°C (140°F) to avoid crystallization of concentrated wastes. Valving of the tank is arranged to permit pumping the contents back to the waste pretreatment facility in the event of a malfunction in the bitumenization facility. Slurries can be dewatered in the tank by draining excess water through a filter.

The processing of dry, particulate solid secondary wastes will require the addition of a dry waste feeder to the FRP solidification facility. A schematic drawing of one type of dry waste feed system is shown in Figure 4.7.8. Dry waste, such as ashes, would be transferred pneumatically or by gravity flow to the dry waste hopper. The exhaust air would be passed through a suitable filter system to assure adequate retention of dusts and aerosols (less than 10^{-6} fraction release to the process off-gas treatment system).

Bitumen Feed System. The bitumen feed system is provided to store the bulk bitumen, maintain the bitumen in a liquid state, and meter the proper quantity of the binder to the extruder-evaporator to achieve the desired ratio of bitumen to waste in the end product. This system consists of a bitumen storage tank, transfer pumps, inlet and outlet strainers, metering pump, and the required instrumentation and controls. All systems are steam heated and insulated to maintain the bitumen at a minimum of 120°C (248°F) to ensure that proper flow properties are maintained. The bitumen storage tanks are made of carbon steel and have a capacity of 34 m³ (9000 gal).

Screw Extruder-Evaporator. The major sections of the extruder-evaporator are the motor drive and process sections. Figure 4.7.9 shows an extruder-evaporator unit. This unit has a maximum evaporation capacity of 120 kg/hr (32 gal/hr) and an end-product volume rate of 0.032 to 0.064 m³/hr (8.5 to 17 gal/hr) for liquid feeds. Nominal operating capacity of the FRP bitumenization facility has been assumed to be 120 kg/hr boil-off rate for liquid waste feed and 3 drums/hr of solidified product for solid waste feeds.

The motor drive is typically a 50- to 100-hp motor connected to a reduction and distribution gear. The gearbox is equipped with a forced lubrication system that supplies oil to all gears and bearings. The design of the extruder-evaporator allows for a shielding wall to be placed between the drive and process section, thus providing access to the drive section while minimizing operator exposure.

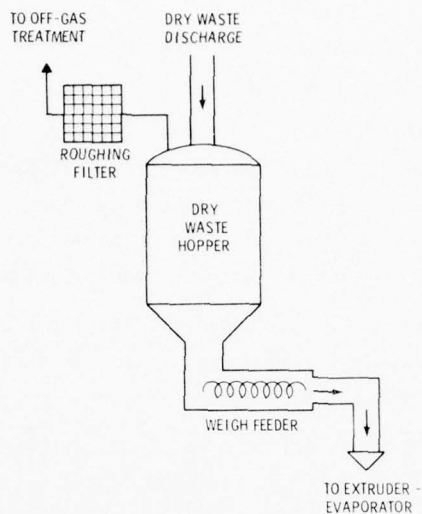


FIGURE 4.7.8. Dry Waste Feed System

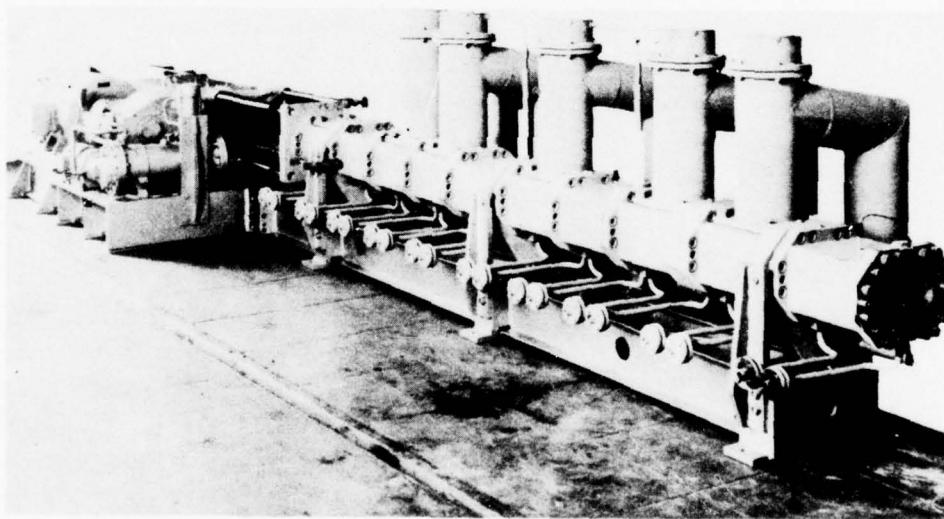


FIGURE 4.7.9. Screw Extruder-Evaporator (Courtesy of the Werner and Pfleiderer Corporation)

The process section has two co-rotating screws. These screws consist of screw shafts with fitted kneading and conveying sections of different pitch and length, each fixed to the shafts by a key. The screw profile is intermeshing with about 1 mm clearance between the corresponding parts of the two rotating elements, providing self-wiping and cleaning. The extruder screws pass through housings (barrel sections) that are tightly bolted together. These housings are interchangeable and are supported by plates that rest on the machine base frame. Both the screw housings and the screw elements are made of nitrided steel.

Heating steam flows through interconnected axial bores within the housing walls to heat the process section. Steam inlets and outlets are in the housing flanges. The units use

saturated steam (220°C, 300 psig). Cooling water is supplied to the inlet and outlet sections of the extruder-evaporator to aid in mixing.

Steam domes are mounted on top of the barrels with vent openings to convey the evaporated water to an integral condenser. The steam domes are equipped with steam injection nozzles to clean their inside surfaces. Process distillate is drained by gravity to the distillate collection and transfer system. The distillate is pumped through a small cartridge oil filter to a 3-m³ distillate collection tank from which it is conveyed to the general purpose concentrator.

Filling and Capping Stations. The container filling and capping operations take place in a shielded area to minimize radiation exposure to the operator and other personnel. The operator can monitor and control all aspects of these operations from the system control panel.

Located within the container filling area is the discharge barrel of the screw extruder. A transfer cart, which holds three drums, indexes to the drum filling position for a one-cycle drum fill. Filled drums are then transported to the capping station where the drums are remotely capped, as Figure 4.7.10 shows.

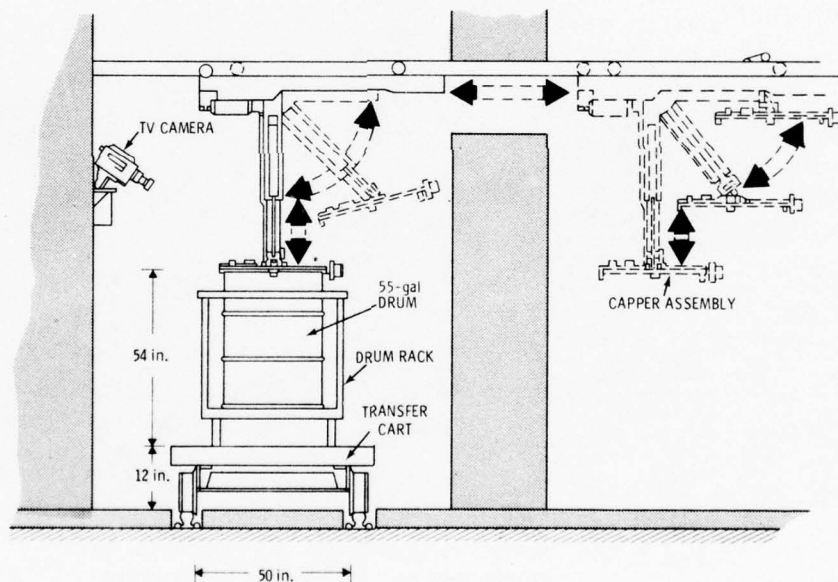


FIGURE 4.7.10. Remote Control Drum Capper and Transfer Cart

Inspection and Decontamination Stations. After being capped, the filled drums are moved to the inspection and decontamination stations. In this area, swipes are taken with a special extension tool through a shield wall to determine the presence of smearable contamination. If contamination is present, the drums are decontaminated with a steam and water spray. Additional swipe tests and decontaminations are done until the filled drum is shown to be free of surface contamination.

Container Transfer Cart. The container transfer cart is shown in Figure 4.7.10. Its movement path is shown in Figure 4.7.5. The cart is sized to carry three drums at any one time. Within one filling cycle, three empty drums are loaded onto the cart and carried into the processing cell for filling. After filling, the drums are carried through the capping and decontamination stations and finally into the storage area. After the drums are unloaded, the process is repeated.

Bridge Cranes. As Figure 4.7.5 shows, two bridge cranes are used in the FRP BIF. They are remotely operated 6-ton bridge cranes, one located in the processing cell and one in the storage area. Both cranes are controlled from the operating gallery.

The cranes have a variety of uses. The processing cell crane is available for placing spent cartridge filters into empty drums, as well as for maintenance. The filled drum storage area crane is used to remove drums from the transfer carts, to move drums into carts, and to load drums onto transport vehicles. Both cranes are available for use in accident conditions, if needed.

Control Module. The FRP BIF is remotely operated from a central control panel from which all operating functions can be controlled and monitored. The reference system and controls are designed for operation by one person. In addition to the main control panel, a separate control panel is provided for container handling operations. Full control and observation of crane and other container handling controls are provided on this panel.

Visual access is provided to the fill chamber and to subsequent capping and monitoring operations by shield windows and closed-circuit television monitors. Each camera and motorized lens assembly is mounted in a dust-tight enclosure to protect the camera and lens from contamination. Fixed position and motorized pan with tilt mounting are included. The system includes two monitors in the main control panel; two monitors at the crane control panel; two cameras with fixed focus lens; four cameras with pan, tilt, and zoom lens; and one set of system controls and switching units.

Shielding. At the FRP BIF, operators are protected during normal operation by 0.9 m (3 ft) of concrete shielding. This assures the capability of processing wastes that contain a maximum radioisotope concentration of 4000 Ci/m^3 (100 Ci/ft^3) of mixed fission products. Dose rates in the operating areas will not exceed 0.5 mrem/hr.

4.7.1.5 Operating and Maintenance Requirements for the Bitumen Immobilization Facility at the Fuel Reprocessing Plant

The reference FRP BIF is highly automated and is operated remotely. Operation of the facility is on an intermittent, as-needed basis. In processing primary TRU wastes, the system operates 2050 hr/yr. Immobilization of secondary TRU wastes requires 3140 hr/yr of operation. (The hours required for secondary TRU waste processing are largely spent in the processing of incinerator blowdown solution, as Table 4.7.4 shows.)

Contact maintenance is used in the FRP BIF. The system is designed with major components located in separate cubicles for ease of operation and maintenance. Radiation levels are reduced when needed for maintenance by flushing the waste feed system and recycling the flush to the primary facility radioactive waste system. The extruder is largely self-cleaning because of the conveying and self-wiping action of the screw elements. To reduce the thin film of waste-bitumen mixture that remains on the screw assembly surfaces, it is necessary to operate the steam dome jets. This type of cleaning needs to be done only when the screw assemblies are to be removed for inspection. Based on the operating experience, this inspection, which can typically be done in less than 2 hr, should be scheduled approximately once every 4000 hr of operation or annually. Typically, residual radiation levels at the extruder during a shutdown have measured less than 10 mR/hr, even after having operated with waste feed streams that have a specific activity of 1000 Ci/m^3 of mixed fission products.⁽²⁾

Staffing Requirements. Average manpower requirements for the FRP BIF are summarized in Table 4.7.5.

TABLE 4.7.5. Staffing Requirements for the Fuel Reprocessing Plant Bitumen Immobilization Facility

Waste Processed	Manpower Requirements, man-yr/yr		
	Operators	Radiation Monitors	Maintenance Craftsmen
Primary waste	1.6	0.2	0.4
Miscellaneous secondary solutions	0.2	0.03	0.05
Incinerator ash	0.1	0.02	0.03
Incinerator blowdown	1.9	0.3	0.5
Facility total	3.8	0.6	1.0

Supplies and Utilities. Based on primary waste, miscellaneous secondary solution, incinerator ash and incinerator scrubber solution immobilization times of 2050 hr/yr, 260 hr/yr, 100 hr/yr and 2,780 hr/yr, respectively, supply requirements for the FRP BIF are shown in Table 4.7.6; utility requirements are given in Table 4.7.7.

Hazardous Materials. No unduly hazardous materials are involved in the operation of the FRP BIF. Bitumen is combustible, although only at high temperatures. The steep roofing type of bitumen used by these systems has a flashpoint of about 290°C (554°F) and a burning point of about 440°C (824°F).⁽²⁾ Those temperatures are well above the highest temperature reached in the process system (175°C or 347°F).

The incorporation of radioactive wastes into bitumen does not substantially alter the flashpoint or burning point. Tests have shown that the temperature of spontaneous combustion of radioactive waste and bitumen mixtures is greater than 350°C (762°F).⁽²⁾ Furthermore, a bitumen fire can be easily extinguished with CO_2 .

TABLE 4.7.6. Supply Requirements for the Fuel Reprocessing Plant Bitumen Immobilization Facility

Waste Processed	Annual Supply Requirements	
	Drums (a)	Bitumen, (b) kg
Primary waste	1308	1.9×10^5
Miscellaneous secondary solutions	78	1.0×10^4
Incinerator ash	298	3.9×10^4
Incinerator blowdown	<u>844</u>	<u>1.1×10^5</u>
Facility total	2528	3.5×10^5

a. DOT Specification 17C, 55-gal (0.21 m^3) drums.

b. Bitumen is steep roofing type and has the following characteristics:

Softening point	88° to 93°C
Flash point	$\sim 290^\circ\text{C}$
Density	$\sim 1000 \text{ kg/m}^3$
Solubility in CCl_4	$>99.0\%$

TABLE 4.7.7. Utility Requirements for the Fuel Reprocessing Plant Bitumen Immobilization Facility

Waste Processed	Annual Utility Requirements			
	Electricity, kWh (a)	Water Consumed, (b) m^3	Instrument Air, (c) m^3	Steam, (d) kg
Primary waste	1.6×10^5	3.3×10^2	1×10^4	4.3×10^5
Miscellaneous secondary waste	2.6×10^4	4.6×10^1	1.5×10^3	5.9×10^4
Incinerator ash	1.0×10^4	1.8×10^1	6.0×10^3	2.3×10^4
Incinerator blowdown	<u>2.8×10^5</u>	<u>5.1×10^2</u>	<u>1.7×10^4</u>	<u>6.4×10^5</u>
Facility total	4.8×10^5	9.0×10^2	3.6×10^4	1.2×10^6

a. Use rate of 100 kW.

b. Use rate of $0.2 \text{ m}^3/\text{hr}$.

c. 80 to 100 psig, use rate of $6 \text{ m}^3/\text{hr}$.

d. 300 psig, 217°C , use rate of 230 kg/hr .

4.7.1.6 Secondary Radioactive Wastes for the Bitumen Immobilization Facility at the Fuel Reprocessing Plant

Operation of the solidification facilities produces secondary wastes with characteristics comparable to the primary wastes. It is estimated that uncompacted general trash (disposable clothing, plastic, paper, tools, etc.) is generated at a rate of 0.004 m^3 per drum of waste solidified plus 0.001 m^3 per man-hour of operation. Liquid decontamination and flush solutions are estimated to be generated at a rate of 0.002 m^3 per m^3 of wet waste feed. Total

secondary radioactive waste quantities generated in treating primary TRU wastes at the FRP BIF are shown in Table 4.7.8.

TABLE 4.7.8. Reprocessing Plant Bitumen Immobilization Facility Secondary Radioactive Wastes

Description	Volume, m ³ /yr	Radioactivity Factor(a)
Combustible and compactable waste	9	10 ⁻⁶
HEPA filters	2	10 ⁻⁶
Wet waste	1	10 ⁻³
Solid noncombustible, noncompactable waste	1	10 ⁻⁶
Oil filters ^(b)	0.03	10 ⁻⁴

a. Fraction of input activity, (Table 4.7.2) in secondary wastes.

b. Added to drums prior to filling.

4.7.1.7 Emissions from the Bitumen Immobilization Facility at the Fuel Reprocessing Plant

No liquid process effluents are released to the environment. Condensed process steam and cooling water are recycled within the FRP via closed primary loops isolated for the secondary heating and cooling systems.

Off-gases are vented to the facility off-gas system from various sources, as summarized in Table 4.7.9. As shown earlier in Figure 4.7.3, the FRP BIF off-gas is cycled through a HEPA and charcoal filter prior to discharge to the FRP APS. Via the process off-gas, 1×10^{-4} of the BIF input ^{129}I and 1×10^{-9} of the remainder of the BIF input radionuclides are released to the FRP APS.

Another release pathway for airborne radionuclides has been identified for the FRP BIF. Secondary liquids generated in facility operation, such as the process distillate and the various decontamination solutions, are routed to the FRP general purpose concentrator. The overheads of the general purpose concentrator are either recycled (50%) or are sent to the FRP excess water vaporizer. Once the overheads reach the excess water vaporizer, they are released to the stack with no further treatment. The bottoms of both the general purpose concentrator and excess water vaporizer are routed to the BIF as concentrated secondary waste for immobilization. By this pathway, 3×10^{-12} of the nonvolatile feed BIF radionuclides are estimated to be released to the environment along with essentially all BIF input tritium.

An estimate of the integrated release due to minor accidents, Section 4.7.1.9, for this facility is included in Table 4.7.9. It was developed by weighing the minor accident releases by their expected frequencies and summing the quantities for all identified minor accidents. In addition, a contingency was included in the integrated release to account for unidentified

minor accidents and to compensate for the uncertainty in expected frequency information. Estimated integrated annual releases due to minor accidents for this technology are shown in Table 4.7.9.

Radioactive releases resulting from operations in the FRP BIF are in the form of particulate aerosols composed of salts, both soluble and insoluble, and insoluble oxides.

TABLE 4.7.9. Emissions from the Fuel Reprocessing Plant Bitumen Immobilization Facility

Emission	Description	Annual Quantity		Radioactivity Release Factor to Atmosphere(a)	
Gaseous	Process off-gas	Air	$4.3 \times 10^6 \text{ m}^3$	^3H	1×10^{-9}
				^{129}I	1×10^{-4}
				Others	1×10^{-13}
	Vaporized excess water	H_2O	$2.7 \times 10^5 \text{ kg}$	^3H	1.0
				^{129}I	1×10^{-6}
				Others	3×10^{-12}
	Minor accident integrated annual release			All	6×10^{-15}
Cooling tower water	Evaporated (T = 38°C)		$7.4 \times 10^5 \text{ kg}$		
	Drift (T = 38°C)		$3.6 \times 10^3 \text{ kg}$		
	Blowdown (T = 27°C)		$1.3 \times 10^5 \text{ kg}$		
Other	Heat		$5.0 \times 10^2 \text{ MW-hr}$		
			$(1.7 \times 10^9 \text{ BTU})$		

a. Fraction of input activity (Table 4.7.2) released to atmosphere. Includes DF from main plant APS where applicable. Release over 220 days/yr.

No nonradiologic liquid or gaseous effluents have been identified for the FRP immobilization facility. No lead, arsenic, nickel, mercury, beryllium nor any other such potential toxic nonradioactive substance has been identified as a feed stream to the FRP immobilization facility; thus no such material is released.

In the bitumenization of primary wastes, heat releases are estimated to be $1.4 \times 10^6 \text{ MJ/yr}$ ($1.3 \times 10^9 \text{ BTU/yr}$), with about half of this amount discharged in the condensate cooling water and about half to the air.* During secondary waste immobilization, heat releases are approximately 430 MJ ($4.1 \times 10^5 \text{ BTU}$) per hour of operation, plus 2660 MJ ($2.5 \times 10^6 \text{ BTU}$) per m^3 of water contained in the waste.

* The condensate cooling water discharges its heat to a secondary cooling water loop and from there to the atmosphere via discharge to a cooling tower or pond.

During processing, cooling water is used for condensing distillate in the steam dome condensers on the extruder and in the lube oil cooler. The estimated cooling water heat duty requirement is about 2×10^4 kcal/hr plus 600 kcal per kg of distillate. For the flowsheet conditions in solidifying all TRU wastes, the annual cooling water heat duty is about 4.4×10^8 kcal, equivalent to 1.8×10^6 MJ (1.7×10^9 BTU). Cooling water requirements are the makeup requirements of water at the cooling tower, estimated at 488 g H₂O per MW-sec.

4.7.1.8 Decommissioning Considerations for the Bitumen Immobilization Facility at the Fuel Reprocessing Plant

The FRP BIF is designed to last 30 years. The equipment is readily flushable, and it should be possible to chemically decontaminate the equipment and facility to dose rates no greater than about 100 mrem/hr for decommissioning.

4.7.1.9 Postulated Accidents for the Bitumen Immobilization Facility at the Fuel Reprocessing Plant

Identified minor and moderate accident scenarios are listed in Tables 4.7.10 and 4.7.11, respectively. No accidents that could be classified as severe could be realistically postulated for this technology. For purposes of environmental consequence analysis, releases from accidents 4.7.6 (bitumen fire) and 4.7.8 (cell HEPA filter with bitumen fire) have been designated as umbrella source terms (see Section 3.6-Basis for Accident Analyses). Source term categories are cross-indexed by accident number in Appendix A, Section 3.

4.7.1.10 Costs for the Bitumen Immobilization Facility at the Fuel Reprocessing Plant

Capital, operating and levelized unit costs have been estimated in mid-1976 dollars. A complete description of cost estimate bases, assumptions and definitions is given in Section 3.8.

Capital Costs. The capital construction cost estimate for the FRP BIF is summarized in Table 4.7.12.

Operating Cost. The costs for direct labor, materials, and utilities are based on requirements shown in Tables 4.7.5, 4.7.6, and 4.7.7. Process materials consist of bitumen at \$0.105 per kilogram and DOT Specification 17C drums at \$20 each. Maintenance materials costs are estimated at 3% of major equipment. Table 4.7.13 summarizes the operating costs.

Levelized Unit Cost. The levelized unit cost, including levelized capital and operating costs, is shown in Table 4.7.14. The unit cost calculation assumes private ownership of the facilities.

4.7.1.11 Construction Requirements for the Bitumen Immobilization Facility at the Fuel Reprocessing Plant

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating the impact of construction activities.

TABLE 4.7.10. Minor Accidents for the Fuel Reprocessing Plant Bitumen Immobilization Facility

Accident No. and Description	Sequence of Events	Safety Systems	Release
4.7.1 - Spillage during drum filling.	<ol style="list-style-type: none"> 1. Drum fails to index in filling position. 2. Waste spills into cell. 3. Filling stops. 4. Waste repackaged and cell decontaminated. 	<ol style="list-style-type: none"> 1. Detection Systems. ^(b) 2. Cell contains spill. 	None.
4.7.2 - Drum filling control valve failure	<ol style="list-style-type: none"> 1. Valve remains open when drum is filled. ^(a) 2. Waste form spills to floor of cell. 3. Malfunction detected by visual observation, radiation monitor, or level detection equipment. 4. Backup valve closed. 5. Spill is removed and packaged; area is decontaminated. 	<ol style="list-style-type: none"> 1. Detection systems. ^(b) 3. Cell contains spills. 	None.
4.7.3 - Drum fill level detector instrument failure.	<ol style="list-style-type: none"> 1. Level detector fails when drum is filled. 2. Waste form spills to floor of cell. 3. Malfunction detected by visual observation, radiation monitor, or redundant level detector. ^(b) 4. Filling sequence stopped by operator. 5. Spill is removed and packaged; area is decontaminated. 	<ol style="list-style-type: none"> 1. Detection systems. ^(b) 2. Cell containment. 	None.
4.7.4 - Container rupture.	<ol style="list-style-type: none"> 1. Handling equipment malfunctions. 2. Drum falls and is ruptured. 3. Waste form spills to floor of cell. 4. Malfunction detected. 5. All operations stopped. 6. Spill is removed and packaged; area is decontaminated. 	<ol style="list-style-type: none"> 1. Detection systems. ^(b) 2. Cell contains spill. 	None.
4.7.5 - Leak in waste transfer line.	<ol style="list-style-type: none"> 1. Transfer line fails. 2. Contents of feed tank to cell floor. 3. Leak detected. 4. Backup valve closed. 5. Spill is removed and packaged; area is decontaminated. 	<ol style="list-style-type: none"> 1. Detection systems. ^(b) 2. Backup valve. 3. Cell contains spill. 	Less than Accident 4.7.6.

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- a. The bitumen extruder does not have a freeze valve but a catch pan which catches the bitumen-waste mixture while drums are moved. The scenario is similar in that the catch pan may fail to move into position when the drum is filled.
- b. "Detection System" is a generic term used to describe a set of systems which may exist, but, because of the generalized state of the facility design, are not described. Included as detection systems are flow monitors, drums scales, radiation monitors and even visual monitoring by operational personnel.

TABLE 4.7.10. Minor Accidents for the Fuel Reprocessing Plant Bitumen Immobilization Facility (cont'd)

Accident No. and Description	Sequence of Events	Safety System	Release
4.7.6 - Bitumen fire during drum filling.(c) Expected frequency, 0.03 per year.	<ol style="list-style-type: none"> 1. Operational error results in chemically reactive material in feed stream. 2. Fire in filled drum results from spontaneous combustion.(d) 3. Radionuclides volatilized. 4. Fire detected. 5. CO₂ extinguishing system is activated. 6. Cell decontaminated and filters replaced. 	<ol style="list-style-type: none"> 1. Fire detection system. 2. CO₂ fire extinguishing system. 3. Cell filters and APS reduce release to atmosphere. 	Three open barrels of bitumen catch fire during the filling operation. It is estimated that before extinguishment, 1 kg of fixed waste would burn in each barrel. Based on experience with burning solvent in open pans,(e) it is estimated that no more than 1% of the activity in the burned wastes would be released to the atmosphere. This material would be released to the plant stack after processing by the facility HEPA filters (DF = 10 ⁷) in 0.5 hours.

- c. FRP ILLW will produce largest source term. Bitumen fire may occur with equal probability with other feed streams.
- d. W. Bahr, W. Hild and W. Kluger, Bituminization of Radioactive Wastes at the Nuclear Research Center, Karlsruhe. Kernforschungszentrum Karlsruhe report KFK-2119, October 1974.
- e. D. W. Tharn, Burning of Radioactive Process Solvent, USAEC report DP-942, E. I. Dupont de Nemours & Co., Savannah River Laboratory, Aiken, SC, 1965.

TABLE 4.7.11. Moderate Accidents for the Fuel Reprocessing Plant Bitumen Immobilization Facility

Accident No. and Description	Sequence of Events	Safety Systems	Release
4.7.7 - Cell HEPA filter failure with any minor accident.	<ol style="list-style-type: none"> 1. HEPA filter clogs with minor accident. 2. HEPA filter fails. 3. Airborne radioactive material bypasses HEPA filter. 4. Failure detected with pressure differential across HEPA filter. 5. Cell ventilation system automatically shuts off. 6. Filter replaced. 	<ol style="list-style-type: none"> 1. HEPA filter failure detection system. 2. Cell ventilation system shutoff. 	Less than Accident 4.7.8.
4.7.8 - Cell HEPA filter failure with bitumen fire; estimated frequency, 0.003 per year.	<ol style="list-style-type: none"> 1. HEPA filter clogs with minor accident. 2. HEPA filter fails. 3. Airborne radioactive material bypasses HEPA filter. 4. Failure detected with pressure differential across HEPA filter. 5. Cell ventilation system automatically shuts off. 6. Cell decontaminated and filter replaced. 	<ol style="list-style-type: none"> 1. HEPA filter failure detection system. 2. Cell ventilation system shutoff. 	The source term of Accident 4.7.6 is released directly to the FRP APS, bypassing the cell HEPA filter.

TABLE 4.7.12. Capital Cost Estimate for the Fuel Reprocessing Plant Bitumen Immobilization Facility

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		15	2,600	200	2,800
Buildings and structures		75	500	800	1,300
Bulk materials		100	2,100	1,300	3,400
Site improvements					
Subtotal of direct site construction costs		190	5,200	2,300	7,500
Indirect site construction costs	50	40	800	1,000	1,800
Total field cost	50	230	6,000	3,300	9,300
Architect-engineer services					1,600
Subtotal					10,900
Owner's cost					3,100
Total facility cost					14,000
Estimated accuracy range					±25%

TABLE 4.7.13. Operating Cost Estimate for the Fuel Reprocessing Plant Bitumen Immobilization Facility

Cost Element	Annual Costs, \$1000s	
Direct labor	100	
Process materials	120	
Utilities	35	
Maintenance materials	85	
Overhead	170	
Miscellaneous	40	
Total	550	+50% -25%

TABLE 4.7.14. Levelized Unit Cost Estimate for the Fuel Reprocessing Bitumen Immobilization Facility

Cost Element	Unit Cost, \$/kg HM
Levelized capital charge	1.73
Levelized operating charge	0.27
Levelized total unit cost	2.00 ±35%

Project Schedules and Construction Manpower. The schedule for engineering, procurement, and construction of the FRP BIF is an integral factor in the overall schedule for the construction of the FRP. The field labor force estimated for the construction of the FRP BIF is tabulated below:

	Man-hours, 1000s
Manual field labor	230
Nonmanual field labor	50
Total field labor	280

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials, and services provided at the site of the FRP; offsite costs are those for all services provided, equipment fabricated and/or assembled, and material purchased elsewhere. The distribution of total costs in these categories is as follows:

	Costs, \$1000s
Onsite	4,000
Offsite	11,000
Total	15,000

Site Requirements. The BIF requires 860 m^2 (6000 ft^2) within the FRP site.

Water. Water used during the construction period is approximately 3400 m^3 ($0.9 \times 10^6 \text{ gal}$).

Construction Materials. Materials committed to facility construction are:

Concrete	1400 m^3	(1800 yd^3)
Steel	360 MT	(400 tons)
Copper	7 MT	(8 tons)
Lumber	80 m^3	(35 MFBM)

Energy. Energy resources used during construction are:

Propane	30 m^3	(8,000 gal)
Diesel fuel	320 m^3	(85,000 gal)
Gasoline	210 m^3	(55,000 gal)
Electricity		
Peak demand	250 kW	
Total consumption	160,000 kWh	

Transportation Requirements. No separate transportation requirements for the FRP BIF have been identified beyond those for the FRP.

4.7.1.12 Effects of Fuel Cycle Options

The FRP BIF would not be required for the once-through fuel cycle since there is no fuel reprocessing. The facility and process described here apply to either uranium recycle or uranium-plutonium recycle.

4.7.2 Cement Immobilization at a Fuel Reprocessing Plant

Except for the fuels receiving and storage facility wastes that resemble nuclear power plant wastes, there is very little industrial experience in solidifying typical FRP wastes with available cementation systems. Thus, adapting commercially available cementation systems to FRP wastes requires some extrapolation of demonstrated capabilities. The immobilization of the nontransuranic (non-TRU) wastes, such as those from the fuels receiving and storage facility, is not included in the scope of this report and will not be discussed. However, treatment facilities have been sized to accommodate both the TRU and non-TRU FRP wastes. Wastes and their sources are the same as those listed earlier in Tables 4.7.1 and 4.7.2, and illustrated in Figure 4.7.1.

4.7.2.1 Cementation Process Alternatives at the Fuel Reprocessing Plant

Several different types of cement immobilization facilities (CIF) are commercially available. These include in-drum mixers, drum tumblers, and in-line mixers, each of which is described.⁽⁴⁾ A drum-tumbling system, similar to the system manufactured by the Stock Equipment Company for immobilization of reactor radioactive wastes, has been selected as the reference FRP CIF. This drum-tumbling system was selected because of its ability to process both liquid and dry wastes. In addition, the wastes are mixed inside the container in which the mixture is shipped and disposed of; thus the possibility of external freezing of the waste-cement mixture is avoided.

4.7.2.2 Design Basis for the Cement Immobilization Facility at the Fuel Reprocessing Plant

The FRP CIF is used to convert all aqueous solutions, slurries, and dry particulate solids containing substantial levels of fission products and transuranics to liquid-free monolithic solids to be contained in DOT Specification 17C, closed-top, 55-gal drums with screw-capped openings 0.1 m (4 in) in diameter. The FRP CIF has a capacity of two to three drums of solidified waste per hour and is capable of processing FRP wastes contaminated with as much as 1000 Ci per m³ of mixed fission products. Both TRU and non-TRU wastes can be immobilized in the FRP cementation facility. Administrative and operating controls will maintain the segregation of the two waste types, with processing campaigns for each waste type.

4.7.2.3 Process for the Cement Immobilization Facility at the Fuel Reprocessing Plant

In the operation of the FRP CIF a weighed amount of cement powder and a mixing weight are added to the waste disposal drum before transfer to the fully-enclosed waste filling station. After filling with waste and capping, the drum is rotated end-over-end for a few minutes. The drum is then inspected and moved to storage prior to transport and disposal.

The FRP CIF flow diagram, modified to include a conceptual process for handling dry particulate wastes, is shown in Figure 4.7.11. The process begins with the receipt, inspection, and storage of empty drums. When an empty drum is to be filled with waste, it is removed from storage and transported on a roller conveyor to the cement filling station where a mixing weight is manually inserted into the filling connection of the drum. Cement is weighed into the drum from a cement storage silo equipped with its own bag type of dust

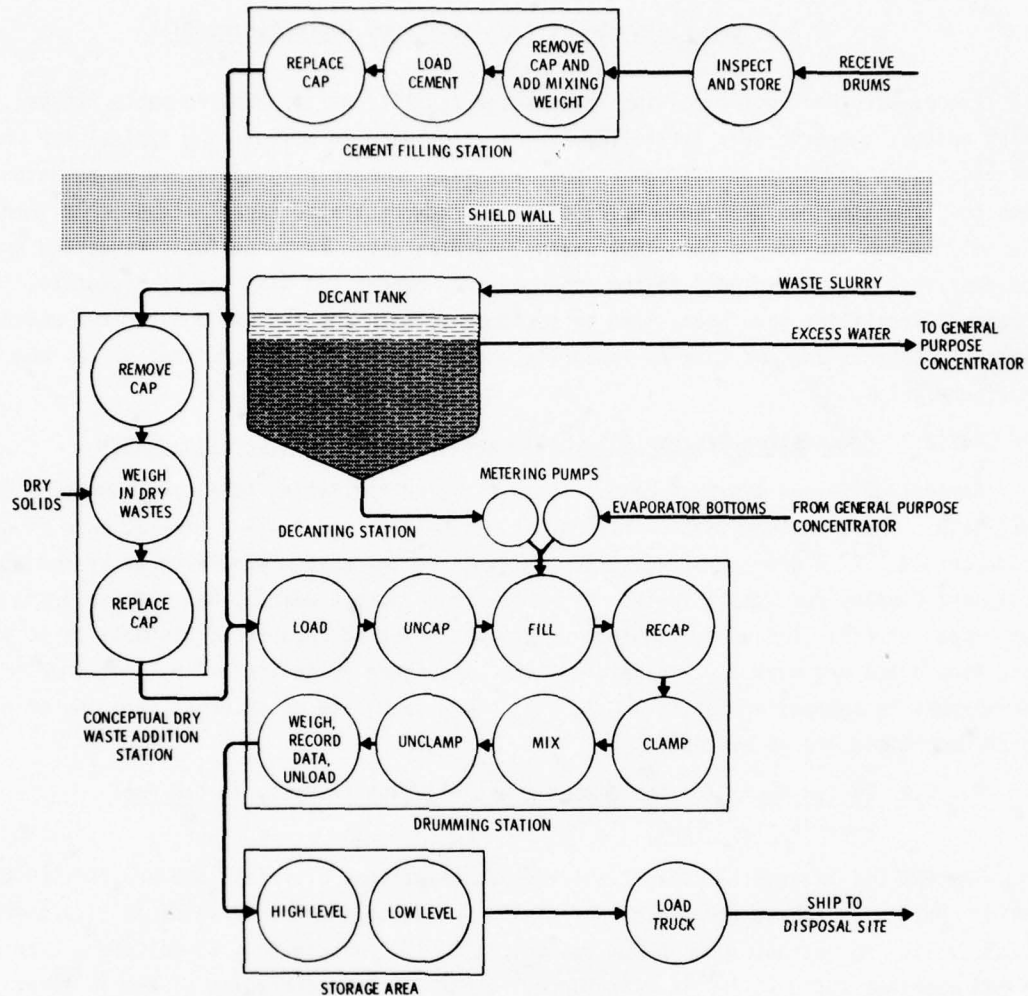


FIGURE 4.7.11. System Flow Diagram for the Fuel Reprocessing Plant Cement Immobilization Facility

collector. The cap is replaced on the drum, and the drum is transported to the enclosed drumming station. The facility operator then starts an automatic fill cycle in which the drum is uncapped, filled, capped, and mixed by end-over-end tumbling, after which the drum returns to the load-unload position. With the double-fill option selected for the FRP CIF, additional waste is then added and the tumbling operation is repeated. This procedure increases the drum loading from a 75% fill to a 90% fill. The processing enclosure is provided with two spray systems for decontamination of both the enclosure and the drum if contamination is detected when the hatch is opened. Spills and decontamination water are contained in the enclosure and routed to the contaminated drain system. After passing inspection, the drum is moved to a scale platform by crane where it is weighed and the radiation level is measured. The drum is then transferred by crane to a shielded storage area, where containers are segregated according to radiation level and TRU content, and from there to truck loadout.

A decant tank is provided to remove excess water from waste slurries. After the solids have settled out, excess water is pumped off and returned to the waste slurry storage tank, leaving sufficient water to obtain a proper mix with the cement. A tank mixer is then used to remix the remaining water with the settled material and to keep the mixture homogeneous prior to drum filling.

The conceptual dry waste process shown in Figure 4.7.11 is used to immobilize dry wastes such as incinerator ashes and zeolites. The drum would be placed in the dry waste addition station, the cap removed, and the dry wastes metered according to a predetermined formulation. The cap would then be replaced and the exterior of the drum decontaminated, if necessary, before transfer by crane to the liquid waste drum processing enclosure where the required amount of liquid waste would be added to provide a good mix.

Waste-cement mixtures are predetermined by analysis and laboratory testing to optimize the performance of the cement product. Tables 4.7.15 and 4.7.16 shows typical mixing ratios for various types of wastes. Based on Tables 4.7.15 and 4.7.16, the untreated waste characterization in Table 4.7.2, and on a 90% drum fill, material and process flow diagrams for processing TRU wastes in the FRP cementation system are shown in Figure 4.7.12 and in Table 4.7.17. The immobilized product of the FRP CIF is characterized in Table 4.7.18. Not shown is the leach rate of cement immobilized radioactive wastes which has been measured at 10^{-1} to 10^{-6} g/cm²-day and 10^{-7} to 10^{-9} g/cm²-day for alkali and alkaline earths, and for actinides and rare earths, respectively.⁽³⁾ As shown in Table 4.7.18, there are three product streams for the FRP CIF. The primary waste and miscellaneous secondary solutions have been composited. The ILLW is used as the added liquid for the immobilization of the fluorinator and silica gel wastes. The added liquid for the immobilization of incinerator ash is 27% of the incinerator scrubber solution. The primary and secondary miscellaneous solution wastes are processed in the CIF as one stream, the incinerator ash as one stream and the incinerator scrubber solution not used with the ash is one stream.

4.7.2.4 Description of the Cement Immobilization Facility at the Fuel Reprocessing Plant

The FRP CIF is assumed to be an integral part of the FRP and will be a Category I structure. The approximate location of the CIF is shown in Figure 4.7.13. The CIF is shown in detail in Figures 4.7.14, 4.7.15, and 4.7.16. The design uses concrete shield walls 0.9 m (3 ft) thick, four separate storage areas for segregating wastes according to radiation levels and TRU content, and an enclosed truck bay. The interior dimensions are 21 x 40 x 7 m (70 x 130 x 23 m). The shielded crane bay is 14 m (46 ft) wide and covers the length of the facility. Working areas include 285 m² (3070 ft²) of shielded storage space, a 110-m² (1190 ft²) truck bay, 44 m² (470 ft²) of empty drum storage, an 18-m² (200 ft²) control room, and 84 m² (900 ft²) for the cement filling station and access corridors. The remaining area is occupied by shield walls and shielded process stations.

TABLE 4.7.15. Fuel Reprocessing Plant Waste-Cement Formulation

Waste	Component per m ³ Solidified Waste				
	Dry Waste or Dewatered Sludge, m ³	Added Water or Waste Concentrate, m ³	Bulk Cement, m ³	Cement, kg	Cement, wt%
Separations and PuO ₂ Facility:					
ILLW ^(a) (30% NaNO ₃ + Na ₃ PO ₄)		0.60	0.82	1230	62
Silica gel (30% H ₂ O)	0.72	0.18	0.23	344	30
UF ₆ Facility:					
Fluorinator beds and fines	0.91	0.20	0.40	600	27

a. Intermediate-level liquid wastes.

TABLE 4.7.16. Secondary Waste-Cement Formulations

Secondary Waste	Added Liquid, wt%	Cement, wt%	Product Density, kg/m ³
Miscellaneous concentrated solution (75 wt% water)		60	1900
Incinerator ash	45 ^(a)	40	1730
Concentrated incinerator scrubber solution (75 wt% water)		60	1900

a. Incinerator scrubber solution used to provide necessary water.

Major Process Equipment. The FRP CIF consists of six basic elements:

- cement filling station
- waste feed system
- drumming station
- inspection and labeling station
- bridge crane
- control console.

Cement Filling Station. The cement unloading, storing, feeding, weighing, and conveying equipment comprises the cement feed system, shown schematically in Figure 4.7.17. The system is designed for low-dust operation with tight joints, special shutoff valves, and dust-free nozzle. Controls and interlocks ensure vacuum conditions within the storage tank and conveyor and around the fill nozzle. Exhaust air is filtered through a bag filter and fan system attached to the cement storage tank.

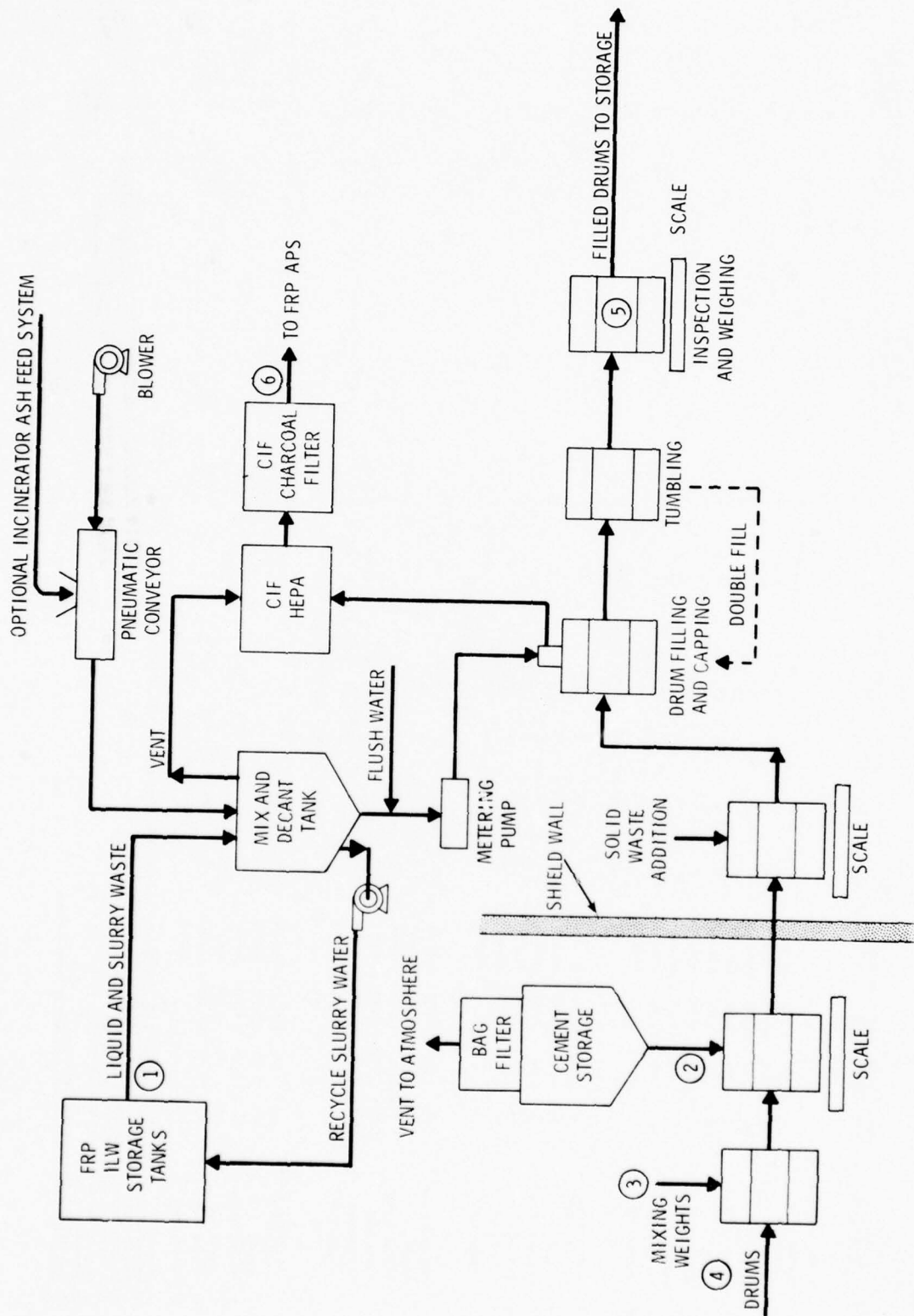


FIGURE 4.7.12. Process Flow Diagram for the Fuel Reprocessing Plant Cement Immobilization Facility

TABLE 4.7.17. Material Balance for the Treatment of Transuranic Waste at the Fuel Reprocessing Plant
Cement Immobilization Facility

Stream Number	Stream Material Description	Volume m ³ /yr	Density kg/m ³	Mass kg/yr	Temperature °C	Number of Drums/yr	Plutonium g/yr	Uranium kg/yr	Fission Product 95Zr + 95Nb	106Ru + 106Rh	129I	Radioactivity (a)			
												All Other Fission Products	Pu	U	All Other Actinides
PRIMARY WASTE															
1	Primary Waste Feed														
	Fluorinator Bed Residues (b)	8	1,500	12,000	Ambient	46 (f)	5	12	1 x 10 ⁻⁵	1 x 10 ⁻⁴	0	0	0.569	0.390	0.817
	Fluorinator Fines (b)	60	1,500	90,000	Ambient	347 (f)	24	2,890	1 x 10 ⁻⁴	0.001	0	0	1 x 10 ⁻⁴	0.002	0
	ILLW (c)	220	1,250	275,000	Ambient	1,777	24,300	1,940	0.99	0.99	0.967	0.80	6 x 10 ⁻⁴	0.585	0
	Silica Gel (c)	10	800	8,000	Ambient	73 (f)	2.4	0	1 x 10 ⁻⁴	0	0	0	6 x 10 ⁻⁵	0	0
2	Cement	310	1,500	465,000	Ambient	0	0	0	0	0	0	0	0	0	0
3	Mixing Weights	1.04	7,800	8,140	Ambient	0	0	0	0	0	0	0	0	0	0
4	Empty Drums	487	115	56,100	Ambient	2,243	0	0	0	0	0	0	0	0	0
5	Filled Drums	487	1,890	919,000	Ambient	2,243	24,300	4,840	0.990	0.991	0.967	0.80	0.570	0.977	0.817
6	Process Vent (e)				Ambient		2 x 10 ⁻⁵	5 x 10 ⁻⁶	1 x 10 ⁻⁹	1 x 10 ⁻⁹	1 x 10 ⁻⁴	8 x 10 ⁻¹⁰	6 x 10 ⁻¹⁰	1 x 10 ⁻⁹	8 x 10 ⁻¹⁰
SECONDARY WASTES - MISCELLANEOUS SOLUTIONS															
1	Miscellaneous Solutions (d)	34	1,200	41,000	Ambient	283	2,200	97	0.001	0.001	6 x 10 ⁻⁴	0.080	0.054	0.019	6 x 10 ⁻⁴
2	Cement	41	1,500	61,200	Ambient	0	0	0	0	0	0	0	0	0	0
3	Mixing Weights	0.1	7,800	1,030	Ambient	0	0	0	0	0	0	0	0	0	0
4	Empty Drums	62	115	7,080	Ambient	283	0	0	0	0	0	0	0	0	0
5	Filled Drums	62	1,780	110,000	Ambient	283	2,200	97	0.001	0.001	6 x 10 ⁻⁴	0.080	0.054	0.019	6 x 10 ⁻⁴
6	Process Vent (e)				Ambient		2 x 10 ⁻⁶	1 x 10 ⁻⁷	1 x 10 ⁻¹²	1 x 10 ⁻¹²	6 x 10 ⁻⁸	8 x 10 ⁻¹¹	5 x 10 ⁻¹¹	2 x 10 ⁻¹¹	6 x 10 ⁻¹³
SECONDARY WASTES - INCINERATOR ASHES															
1	Incinerator Ash (d)	170	230	39,100	Ambient	829 (g)	14,000	19	0.010	0.010	6 x 10 ⁻⁴	0.127	0.361	0.004	0.164
2	Cement	72	1,500	108,000	Ambient	0	0	0	0	0	0	0	0	0	0
3	Mixing Weights	0.4	7,800	3,000	Ambient	0	0	0	0	0	0	0	0	0	0
4	Empty Drums	180	115	20,700	Ambient	829	0	0	0	0	0	0	0	0	0
5	Filled Drums	180	1,620	291,000	Ambient	829	14,000	19	0.010	0.010	6 x 10 ⁻⁴	0.127	0.361	0.004	0.164
6	Process Vent (e)				Ambient		1 x 10 ⁻⁵	2 x 10 ⁻⁸	1 x 10 ⁻¹¹	1 x 10 ⁻¹¹	6 x 10 ⁻⁸	1 x 10 ⁻¹⁰	4 x 10 ⁻¹⁰	4 x 10 ⁻¹²	2 x 10 ⁻¹⁰
SECONDARY WASTES - INCINERATOR SCRUBBER SOLUTION															
1	Incinerator Scrubber Solution (d)	370	1,200	444,000	Ambient	2,230	600	0.48	2 x 10 ⁻⁴	2 x 10 ⁻⁴	0.032	0.002	0.016	1 x 10 ⁻⁴	0.019
2	Cement	320	1,500	482,000	Ambient	0	0	0	0	0	0	0	0	0	0
3	Mixing Weights	1.0	7,800	8,090	Ambient	0	0	0	0	0	0	0	0	0	0
4	Empty Drums	485	115	55,800	Ambient	2,230	0	0	0	0	0	0	0	0	0
5	Filled Drums	485	1,790	870,000	Ambient	2,230	600	0.48	2 x 10 ⁻⁴	2 x 10 ⁻⁴	0.032	0.002	0.016	1 x 10 ⁻⁴	0.019
6	Process Vent (e)				Ambient		6 x 10 ⁻⁷	5 x 10 ⁻¹⁰	2 x 10 ⁻¹³	2 x 10 ⁻¹³	3 x 10 ⁻¹¹	2 x 10 ⁻¹²	2 x 10 ⁻⁴	2 x 10 ⁻¹³	2 x 10 ⁻¹¹

a. Fraction of input radioactivity (Table 4.7.2). The specific isotopes shown are the major contributors to the product radiation dose rate. Iodine is listed for general information.

b. Characterized in Primary Waste Table 3.3.32.

c. Characterized in Primary Waste Table 3.3.31.

d. Characterized in Secondary Waste Table 3.5.1.

e. 820 m³/hr of air.

f. ILLW used as liquid in immobilization.

g. Incinerator Scrubber Solution used as liquid in immobilization.

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TABLE 4.7.18. Treated Waste From FRP Cement Immobilization

Waste Type and Surface Dose Rate Class	Volume (a) m ³ /yr	Density kg/m ³	Volume Ratio Treated/Untreated	Drums Per Year	Radioactivity Factors (b)		
					Fission Products	Actinides	Activation Products
Cement Immobilized Wet and Particulate Wastes							
>10 R/hr (280 R/hr)	530	1,890	1.60	2,526	$^3\text{H} = 1.0$ $\text{I} = 0.967$ $\text{Zr, Nb, Ru, Rh} = 0.990$ Other = 0.860	$\text{U} = 0.996$ $\text{Pu} = 0.623$ Other = 0.803	$\text{All} = 0.989$
Cement Immobilized Incinerator Ash							
>10 R/hr (10.6 R/hr)	174	1,620	1.0	829	$^3\text{H} = 0$ $\text{I} = 6 \times 10^{-4}$ $\text{Zr, Nb, Ru, Rh} = 0.010$ Other = 0.138	$\text{U} = 0.004$ $\text{Pu} = 0.361$ Other = 0.177	$\text{All} = 0.010$
Cement Immobilized Incinerator Scrubber Solution							
<0.2 R/hr (0.05 R/hr)	468	1,790	1.3	2,230	$^3\text{H} = 1 \times 10^{-4}$ $\text{I} = 0.032$ $\text{Zr, Nb, Ru, Rh} = 2 \times 10^{-4}$ Other = 0.002	$\text{U} = 1 \times 10^{-4}$ $\text{Pu} = 0.016$ Other = 0.020	$\text{All} = 0.001$

a. Treated volume based on container volume.
b. Fraction of facility input (Table 4.7.2).

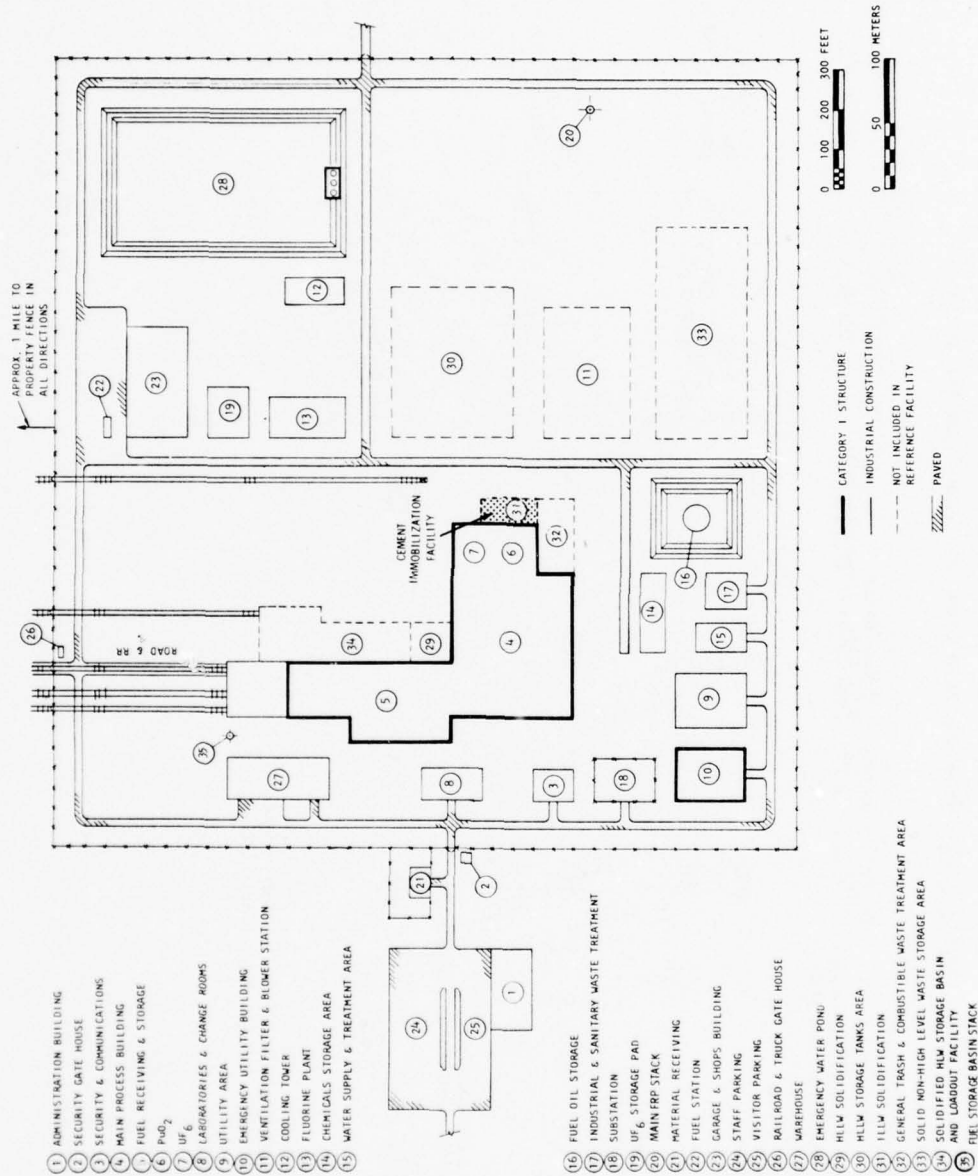


FIGURE 4.7.13. Approximate Location of the Cement Immobilization Facility at the Fuel Reprocessing Plant

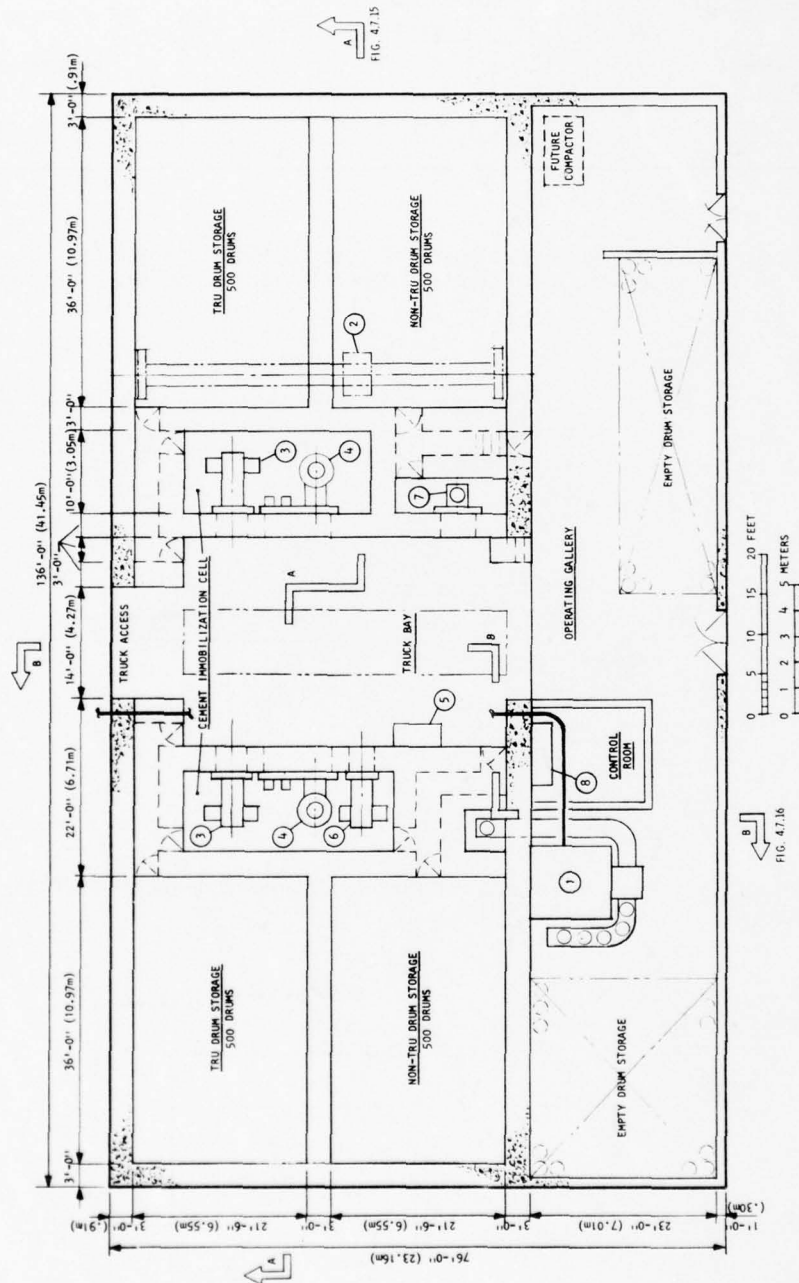


FIGURE 4.7.14. Fuel Reprocessing Plant Cement Immobilization Facility Plan
(Circled numbers refer to the key in Figure 4.7.16.)

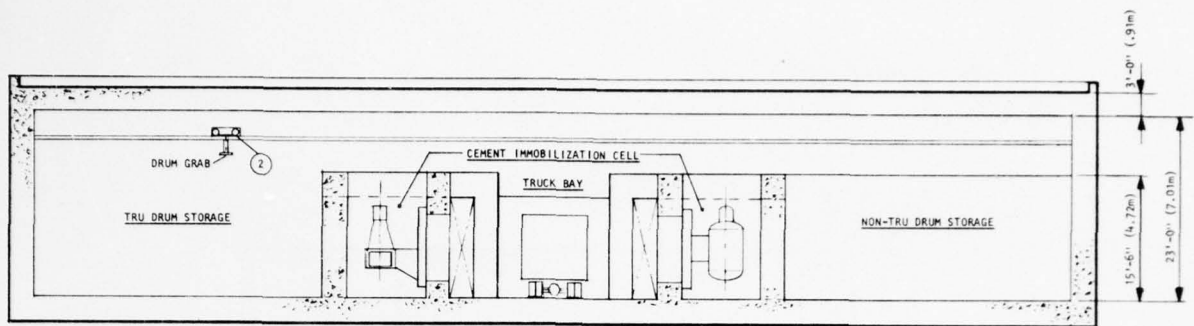


FIGURE 4.7.15. Fuel Reprocessing Plant Cement Immobilization Facility Plan, Section A-A (Circled numbers refer to the key in Figure 4.7.16.)

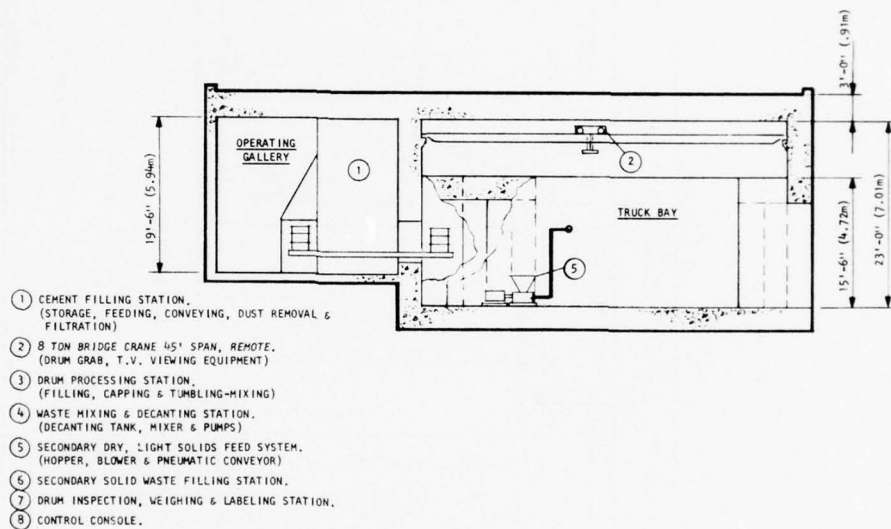


FIGURE 4.7.16. Fuel Reprocessing Plant Cement Immobilization Facility Plan, Section B-B

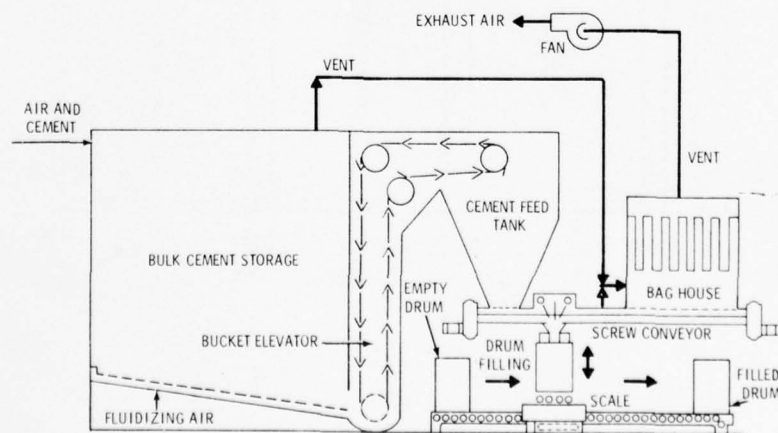


FIGURE 4.7.17. Cement Feed System

The cement storage tank, fabricated from mild steel, has a capacity of 28 m^3 (1000 ft^3); it is 4.4 m (14.5 ft) tall and requires 14 m^2 (150 ft^2) of floor space. The tank fluidizes the cement in an air stream and includes a rotary undercut type of shutoff and flow rate regulatory valve at the outlet. Air for fluidizing the cement is furnished by a 5-hp cast-iron positive displacement rotary blower equipped with a pressure relief valve with intake and exhaust air silencers. A bucket elevator lifts cement from the storage tank into a small (about 2 to 3 m^3) feed tank that discharges into the drum feed screw conveyor.

The drum loading system consists of a drum conveyor, a control cabinet, and a fixed-height fill nozzle surrounded by a dust control plenum. The drum loading system control cabinet is equipped with an elevating mechanism to lift the drum into the load position and an electronic scale to weigh the amount of cement added.

Waste Feed System. The waste feed system is a compact assembly of components designed to remotely decant waste slurries and to pump slurries and concentrated waste solutions to the drums for immobilization. The equipment is mounted on both sides of a machined-steel shield wall approximately 1.5 x 3 x 0.3 m (5 x 10 x 1 ft) thick for personnel protection during operation and maintenance. The shielding wall bolts to machined inserts in the concrete shield walls of the radioactive waste processing area.

The waste feed system contains the decanting tank, decanting pump, slurry metering pump, concentrated waste metering pump and associated controls and piping mounted on a shield wall. The stainless steel decanting tank is 1.4 m (4.5 ft) in diameter by 1.5 m (5 ft) tall. It has a working capacity of 1.9 m^3 (500 gal). It includes a moveable decanting nozzle, sensors, and a mechanical mixer. An emergency overflow at the top of the tank connects to the plant drain line. The decant tank is vented to the radioactive process vent treatment system. A water spray manifold at the top of the tank provides for internal decontamination for maintenance operations. The motors and actuators are located on the "cold" side of the shield wall.

Dry, particulate wastes require special handling to introduce them into the FRP CIF. Two options appear feasible. For dense solids, a dry weighing system similar to the cement filling station could be used. Light solids, such as incinerator ashes, could be pneumatically transferred to the decant tank or a special mixing station where they would be blended with water or a suitable waste solution. Both systems are conceptual and require specific engineering design.

Drumming Station. The drumming station is designed to immobilize radioactive slurries and solutions in cement in 55-gal drums. It is mounted on both sides of a machined-steel shield wall approximately 1.5 x 3 x 0.3 m (5 x 10 x 1 ft) thick. All motors and as much support equipment as practical are mounted on the cold side of the wall. The shield wall bolts to machined steel inserts that fit into the concrete shield walls of the radioactive waste processing areas.

The drum processing enclosure is mounted on the radioactive or hot side of the shield wall. It provides cap removal, liquid waste filling, recapping, drum tumbling, and the water-steam spray for decontamination of the filled drums. The assembly is completely enclosed to minimize escape of radioactive liquids or aerosols. The enclosure is stainless steel with internal surfaces free of crevices to facilitate internal decontamination by the built-in water-steam spray system. Flush solutions and spills are washed into the plant drain. Several interlocks are provided to minimize spills or external contamination to the drum.

The drum processing enclosure has two external platforms, one for the incoming drum and one for the outgoing drum. An internal transfer platform moves the drum to and from the two operational positions. The drum is lowered by crane into the processing enclosure, and the hatch is closed. The operator then sets the processing controls to automatically carry out the uncapping, filling, capping, and mixing operations according to pretested formulas for the specific mixes. The drum filling nozzle has a concentric passage around the nozzle to vent displaced air to the radioactive process vent line via a replaceable roughing filter. In the mixing position, the drum is firmly clamped and rotated end-over-end at 17 rpm for a period controlled by an adjustable timer. The selected double-fill option repeats the waste addition and tumbling operations. At the end of the cycle, the drum is returned to the unload position, the operator remotely opens the hatch, and the drum is removed by the overhead crane to the loadout platform for weighing and radiation monitoring. The drum is then transferred to the drum inspection and labelling station for loadout. Cycle time is approximately 5 min for uncapping, filling, and recapping. Mix times are variable but average about 8 to 10 min. Total cycle time is approximately 15 min.

Inspection and Labeling Station. A small shielded enclosure is provided with a motor-driven turntable that enables the operator to smear-test and monitor the radiation levels of the drums. A slot provides access to the drum for applying labels. All openings are guarded to prevent direct-line radiation exposure to the operator. A periscope or mirrors are used for viewing. Equipment is mounted on a small steel shield wall.

Bridge Crane. The bridge crane, with trolley and 8-ton hoist, is designed and constructed for precise remote handling of radioactive materials. The hoist is equipped with a specially designed grab for handling 55-gal drums. It is operated from the control room with the aid of television cameras--three pointing downward to view the working area as the drum is being transported and one pointing upward to view an indexing grid mounted on the ceiling. The indexing system provides accurate placement of drums in the storage area. Lamps are provided for lighting the field of view. Two electrical circuits are provided for the trolley, bridge, and hoist--one for the high speed motors and one for the low speed motors. The crane has a span of 15 m (46 ft) and a hoist lift of about 5.7 m (19 ft), sufficient to clear the 4.7 m (15.5 ft) shield walls. The equipment can be washed down for decontamination while crane maintenance is carried out in the truck bay.

Control Console. The control console is a desk type of free-standing, dust-tight enclosure. All control and indicating devices required for remote operation of the decanting

station, drumming station, and bridge crane are located on this console. The console is placed in a small control room equipped with a record board for recording the location of stored waste drums.

Shielding. The FRP CIF is designed to be operated and maintained with a minimum of personnel exposure. Use of integrated, automatic control system and closed circuit television permits totally remote operation and monitoring of the entire waste processing and container filling procedure. Operators are protected by concrete 0.9 m (3 ft) thick and by steel shield walls 0.3 m (1 ft) thick; the latter are equivalent to about 1 m of concrete. This shielding ensures the capability of processing feeds that contain the maximum expected radioactive material concentration of about 4000 Ci/m^3 (100 Ci/ft^3) of mixed fission product activity. Dose rates in the operating areas should not exceed 0.5 mrem/hr. For most of the waste, dose rates at the operator's position should be immeasurable above normal plant background.

4.7.2.5 Operating and Maintenance Requirements for the Cement Immobilization Facility at the Fuel Reprocessing Plant

The FRP CIF is highly automated and operated from a remote console. All observations of the waste operations are monitored by closed circuit television or periscope. The facility operates on an intermittent, as-needed basis. Operating hours for primary waste, miscellaneous secondary solutions, incinerator ash, and incinerator scrubber solution immobilization are 750 hr/yr, 95 hr/yr, 280 hr/yr, and 750 hr/yr, respectively.

The FRP CIF is designed so that equipment can be flushed and decontaminated for ease in maintenance. Containment systems are provided to control the generation and dispersion of aerosols and to filter aerosols from the off-gas streams, if necessary, before discharging them to the FRP APS.

Many high maintenance items in the FRP CIF are mounted on the cold side of the steel shield wall. Occasional direct maintenance may be required on the hot side of the wall. All facilities in the hot processing areas can be remotely flushed to reduce general direct maintenance activity levels below 100 mrem/hr. Modular design and addition of shield walls between process components also reduce radiation exposure. Total estimated maintenance radiation exposure is less than 1 man-rem/yr.

Staffing Requirements. Direct staffing requirements of the FRP CIF are summarized in Table 4.7.19.

Supplies and Utilities. Supply and utility consumptions for primary and secondary waste immobilization are shown in Tables 4.7.20 and 4.7.21, respectively.

Hazardous Materials. No unduly hazardous materials are involved in the operation of the FRP CIF.

4.7.2.6 Secondary Radioactive Wastes for the Cement Immobilization Facility at the Fuel Reprocessing Plant

Secondary radioactive wastes generated at the FRP CIF are summarized in Table 4.7.22.

TABLE 4.7.19. Staffing Requirements for the Fuel Reprocessing Plant Cement Immobilization Facility

Waste Processed	Manpower Requirements, man-yr/yr		
	Operators	Radiation Monitors	Maintenance Craftsmen
Primary waste	1	0.2	0.3
Miscellaneous secondary solutions	0.1	0.002	0.04
Incinerator ash	0.4	0.6	0.1
Incinerator blowdown	1.0	0.2	0.3
Facility total	2.5	0.5	0.7

TABLE 4.7.20. Supply Requirements for the Fuel Reprocessing Plant Cement Immobilization Facility

Waste Processed	Annual Supply Requirements	
	Drums (a)	Cement, kg (b)
Primary waste	2243	4.7×10^5
Miscellaneous secondary solutions	283	6.1×10^4
Incinerator ash	829	1.1×10^5
Incinerator blowdown	2230	4.8×10^5
Facility total	5585	1.1×10^6

a. DOT Specification 17C, 55-gal drums; mixing weights are used in each drum.

b. Portland cement.

TABLE 4.7.21. Utility Requirements for the Fuel Reprocessing Plant Cement Immobilization Facility

Waste Processed	Annual Utility Requirements		
	Electricity, kWh (a)	Water Consumed, m ³ (b)	Process Air, m ³ (c)
Primary waste	3.8×10^4	5.3×10^1	6.4×10^3
Miscellaneous secondary solutions	4.8×10^3	6.7	8.0×10^2
Incinerator ash	1.4×10^4	1.8×10^1	2.4×10^3
Incinerator blowdown	3.8×10^4	5.3×10^1	6.4×10^3
Facility Total	9.5×10^4	1.3×10^2	1.6×10^4

a. Use rate of 50 kW

b. Use rate of 0.07 m³/hr

c. 60 to 80 psig, use rate of 8.5 m³/hr

TABLE 4.7.22. Secondary Radioactive Wastes for the Fuel Reprocessing Plant Cement Immobilization Facility

Description	Volume, m ³ /yr	Radioactivity Factor(a)
Combustible and compactable waste	9.8	10 ⁻⁶
HEPA filter	3.2	10 ⁻⁶
Wet wastes	0.6	10 ⁻³
Solid noncompactable and noncombustible wastes	2.4	2 x 10 ⁻⁶

a. Fraction of input activity (Table 4.7.2) in secondary waste.

4.7.2.7 Emissions From the Cement Immobilization Facility at the Fuel Reprocessing Plant

No liquid effluents are released to the environment during routine operation of the FRP CIF. Various liquid streams are recycled within the FRP as secondary wastes and are subsequently concentrated and immobilized.

Vessel and process off-gas vents discharge about 210 m³/hr (120 cfm) of air into the building ventilation system. The immobilization facility ventilation system will then discharge about 36,000 m³/hr (21,000 cfm) of air to the FRP APS and stack. Via the process off-gas vent, 1×10^{-4} of the CIF input iodine and 1×10^{-9} of the remaining nonvolatile CIF input radionuclides are estimated as being released to the FRP APS. As discussed in Section 4.7.1.7, the concentration of secondary liquid wastes provides a pathway for radioactive effluent release; 3×10^{-12} of the CIF input nonvolatile radionuclides are estimated as being released to the environment from the excess water vaporizer, along with 1×10^{-3} of the CIF input tritium.

An estimate of the integrated release due to minor accidents, Section 4.7.2.9, for this facility is included in Table 4.7.23. It was developed by weighing the minor accident releases by their expected frequencies and summing the quantities for all identified minor accidents. In addition, a contingency was included in the integrated release to account for unidentified minor accidents and to compensate for the uncertainty in expected frequency information. Estimated integrated annual releases due to minor accidents for this technology is shown in Table 4.7.23.

Heat released from the FRP CIF comes from equipment operation and from the hydration reaction with cement. Release rates are 31 kW (1.0×10^5 BTU/hr) and 0.015 kWh (51 BTU) per kg of cement, respectively. Thus, heat releases from primary and secondary waste immobilization are 3.1×10^1 MW-hr/yr (1.0×10^8 BTU/yr) and 4.3×10^1 MW-hr/yr (1.5×10^8 BTU/yr), respectively.

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Noise, odor, and vibrations from the facility are insignificant.

Dominant emissions from the FRP CIF are shown in Table 4.7.23.

TABLE 4.7.23. Emissions from the Fuel Reprocessing Plant
Cement Immobilization Facility

Emission	Description	Annual Quantity		Radioactivity Release Factor to Atmosphere(a)	
Gaseous	Process off-gas	Air	$1.9 \times 10^4 \text{ m}^3$	^3H	1×10^{-9}
				^{129}I	1×10^{-4}
				Others	1×10^{-13}
	Vaporized excess water	H_2O	$1.2 \times 10^3 \text{ kg}$	^3H	1×10^{-3}
				^{129}I	1×10^{-6}
				Others	3×10^{-12}
	Minor accident integrated annual release			All	6×10^{-15}
Cooling tower water	Evaporated (T = 38°C)		$1.1 \times 10^5 \text{ kg}$		
	Drift (T = 38°C)		$5.4 \times 10^2 \text{ kg}$		
	Blowdown (T = 27°C)		$1.9 \times 10^4 \text{ kg}$		
Other	Heat		$7.4 \times 10^1 \text{ MW-hr}$		
			$(2.6 \times 10^8 \text{ BTU})$		

a. Fraction of input activity (Table 4.7.2) released to atmosphere. Includes DF from main plant APS where applicable. Released over 80 days/yr.

4.7.2.8 Decommissioning Considerations for the Cement Immobilization Facility at the Fuel Reprocessing Plant

The FRP CIF is designed to last the 30-year lifetime of the main plant. The system is completely flushable, thus making it possible to decontaminate the equipment and facility to less than 100 mrem/hr for decommissioning.

4.7.2.9 Postulated Accidents for the Cement Immobilization Facility at the Fuel Reprocessing Plant

Postulated accidents for the CIF are discussed in Section 4.7.1.9. The minor and moderate accidents selected as being worst case pertain specifically to the bitumen immobilization of FRP wastes. Thus, the consequences of accidents at the CIF are expected to be less severe than those for the BIF.

4.7.41

4.7.2.10 Costs for the Cement Immobilization Facility at the Fuel Reprocessing Plant

Estimates have been made, in mid-1976 dollars, of incremental capital, operating and levelized unit costs. A complete description of the cost estimate basis, assumptions and definitions is given in Section 3.8.

Capital Costs. The capital construction cost estimate for the CIF is summarized in Table 4.7.24.

Operating Costs. Costs of direct labor, materials and utilities are based on requirements given in Tables 4.7.19, 4.7.20, and 4.7.21. Costs of process materials for cement immobilization at the FRP are cement at \$0.073 per kg, DOT Specification 17C drums at \$20 each, and mixing weights at \$0.086 per kilogram. Maintenance materials costs are estimated at 3% of major equipment. Table 4.7.25 summarizes the operating costs.

Levelized Unit Cost. The levelized unit cost, including levelized capital and operating costs, is shown in Table 4.7.26. The unit cost calculation assumes private ownership of the facilities.

TABLE 4.7.24. Capital Cost Estimate for the Fuel Reprocessing Plant Cement Immobilization Facility

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		20	3,200	200	3,400
Buildings and structures		150	1,300	1,800	3,100
Bulk materials		20	400	200	600
Site Improvements					
Subtotal of direct site construction		190	4,900	2,200	7,100
Indirect site construction costs	50	40	800	1,100	1,900
Total field cost	50	230	5,700	3,300	9,000
Architect-engineer services					1,600
Subtotal					10,600
Owner's cost					3,200
Total facility cost					13,800
Estimate accuracy range					±25%

4.7.2.11 Construction Requirements for the Cement Immobilization Facility at the Fuel Reprocessing Plant

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating the impact of construction activities.

TABLE 4.7.25. Operating Cost Estimate for the Fuel Reprocessing Plant Cement Immobilization Facility

Cost Element	Annual Costs, \$1000s
Direct labor	80
Process materials	190
Utilities	7
Maintenance materials	100
Overhead	150
Miscellaneous	43
Total	570 +50% -25%

TABLE 4.7.26. Levelized Unit Cost Estimate for the Fuel Reprocessing Plant Cement Immobilization Facility

Cost Element	Unit Cost, \$/kg HM
Levelized capital charge	1.70
Levelized operating charge	0.30
Levelized total unit cost	2.0 ±35%

Project Schedules and Construction Manpower. The schedule for engineering, procurement, and construction of the CIF is an integral factor in the overall schedule for the construction of the FRP. The field labor force estimated for the construction of the CIF is tabulated below:

	Man-hours, 1000s
Manual field labor	230
Nonmanual field labor	50
Total field labor	280

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials, and services provided at the site of the FRP; offsite costs are those for all services provided, equipment fabricated and/or assembled, and material purchased elsewhere. The distribution of total costs in these categories is shown below:

	Costs, \$1000s
Onsite	3,600
Offsite	10,200
Total	13,800

4.7.43

Site Requirements. The CIF requires 960 m^2 ($10,000 \text{ ft}^2$) within the FRP site.

Water. Water used during the construction period is approximately 3800 m^3 ($1.0 \times 10^6 \text{ gal}$).

Construction Materials. Materials committed to facility construction are:

Concrete	3000 m^3	(4000 yd^3)
Steel	500 MT	(570 tons)
Copper	0.9 MT	(1 ton)
Lumber	180 m^3	(80 MFBM)

Energy. Energy resources used during construction are:

Propane	30 m^3	(8,000 gal)
Diesel fuel	300 m^3	(80,000 gal)
Gasoline	230 m^3	(60,000 gal)
Electricity		
Peak demand	250 kW	
Total consumption	160,000 kWh	

Transportation Requirements. No transportation requirements for the CIF have been identified beyond those for the FRP.

4.7.2.12 Effects of Fuel Cycle Options

Effects of the fuel cycle option on the CIF are the same as for the FRP BIF, as discussed in Section 4.7.1.12.

4.7.3 Other Immobilization Alternatives at a Fuel Reprocessing Plant

In this section, two classes of alternatives are discussed--alternative feed stream treatments and options in the immobilization technology.

4.7.3.1 Feed Stream Treatment Alternatives at Fuel Reprocessing Plant Immobilization Facilities

Four treatment alternatives for FRP waste streams which impact the BIF and CIF are:

- no incineration of combustible trash
- intermediate-level liquid waste (ILLW) combined with high-level liquid waste (HLLW) solidification
- separate spent solvent incinerator
- main plant bead resins to BIF versus incineration.

No Incineration. With the incineration of combustible and compactable trash at an FRP, large volumes of incinerator off-gas scrub solution (called blowdown) are generated along with smaller volumes of incinerator ash. Both the ash and blowdown are immobilized prior to shipping and disposal. Quantities of ash and blowdown before and after treatment are summarized in Table 4.7.27. If incineration is not selected as the treatment for combustible trash, substantially smaller quantities of supplies, utilities, and manpower are required at the

immobilization facilities, as shown in Table 4.7.28. In addition, without incineration the amount of radionuclides released to the environment from radioactive waste immobilization is somewhat smaller.

If the immobilization facility has no incinerator, throughput is drastically reduced. However, this increases throughput at some other facility. Without incineration, trash must either be packaged without treatment or must be compacted. The decision to incinerate or not must be made after a careful economic, environmental, and safety study.

TABLE 4.7.27. Summary of Ash and Blowdown Immobilization Requirements for the Fuel Reprocessing Plant Incinerator

Waste	Treatment	Volume, m ³ /yr	Density, kg/m ³	Activity, Ci/yr	Drums/Yr
Ash	Untreated	170	230	227,000	
	Bitumen	63	1,300	227,000	298
	Cement	170	1,730	227,000	829
Scrubber Solution	Untreated	370	1,200	9,580	
	Bitumen	180	1,300	9,580	844
	Cement	470	1,800	9,580	2,230

ILLW to HLLW. One alternative treatment of the ILLW is to combine it with the HLLW. If this option is chosen, the major component of the primary feed to the FRP low-level waste immobilization facilities would disappear. Table 4.7.29 shows estimates of the supplies, utilities, and manpower that would be saved by choosing this option.

If the ILLW feed stream were treated otherwise, the design basis for the immobilization facilities would change substantially. Not only would the major feed component be removed, but the major source of radioactive material would also be rerouted. Thus, both the throughput and the shielding requirement would be reduced.

Separate Spent Solvent Incineration. In the reference waste management system, the spent solvent from the FRP is incinerated with the ILW combustible trash. The off-gas scrub for the incinerator effectively scrubs the phosphates that result from burning the spent solvent. An alternative spent solvent treatment is a stand-alone solvent incinerator, as described in Section 4.5. The off-gas from the spent solvent incinerator would be scrubbed to remove the phosphate compounds that result from the burning of the tributyl phosphate (TBP) in the solvent. The resultant volume of scrub solution, or blowdown, would be routed to the FRP concentration system prior to immobilization. The net impact on the immobilization facilities' material, utility, and manpower consumptions would be negligible if the solvent was incinerated in a stand alone system rather than the reference incineration facility.

Main Plant Bead Resins to BIF. An additional variation in primary waste feed is the possibility of routing the main plant bead resins directly to the bitumen immobilization facility rather than to the ILW incinerator. The bead resins are characterized in Table 4.7.30.

TABLE 4.7.28. Effect of Incineration Option on Annual Requirements for Supplies, Utilities and Manpower at the Fuel Reprocessing Plant Immobilization Facilities

Feed Option	Annual Supplies and Utilities						Processing Hours	Manpower, man-yr/yr			
	Drums	Binder, (a) kg	Electricity, kWh	Air, m ³	Steam, kg	Water, (b) m ³		Operators	Radiation Monitors	Maintenance	Total
At Bitumen Immobilization Facility											
Ash	298	3.9 × 10 ⁴	1.0 × 10 ⁴	6.0 × 10 ³	2.3 × 10 ⁴	1.8 × 10 ¹	100	0.1	0.02	0.03	0.2
Scrub solution	844	1.1 × 10 ⁵	3.8 × 10 ⁵	1.7 × 10 ⁴	6.4 × 10 ⁵	5.1 × 10 ²	2780	1.9	0.3	0.5	2.7
Total	1142	1.5 × 10 ⁵	3.9 × 10 ⁵	2.3 × 10 ⁴	6.6 × 10 ⁵	5.3 × 10 ²	2880	2.0	0.3	0.5	2.9
Incineration											
Total without Incineration	1386	2.0 × 10 ⁵	1.9 × 10 ⁵	1.3 × 10 ⁴	4.9 × 10 ⁵	3.7 × 10 ²	2310	1.7	0.3	0.4	2.4
Total with Incineration	2528	3.5 × 10 ⁵	5.8 × 10 ⁵	3.6 × 10 ⁴	1.2 × 10 ⁶	9.0 × 10 ²	5190	3.7	0.6	0.9	5.3
At Cement Immobilization Facility											
Ash	829	1.1 × 10 ⁵	1.4 × 10 ⁴	2.4 × 10 ³	-	4.0 × 10 ³	280	0.4	0.06	0.1	0.6
Scrub solution	2230	4.8 × 10 ⁵	3.8 × 10 ⁴	6.4 × 10 ³	-	1.1 × 10 ⁴	750	1.0	0.2	0.3	1.5
Total	3059	5.9 × 10 ⁵	4.8 × 10 ⁴	8.8 × 10 ³	-	1.5 × 10 ⁴	1030	1.4	0.3	0.4	2.1
Incineration											
Total without Incineration	2526	5.3 × 10 ⁵	4.3 × 10 ⁴	7.2 × 10 ³	-	1.1 × 10 ⁴	850	1.1	0.2	0.3	1.6
Total with Incineration	5585	1.1 × 10 ⁶	9.1 × 10 ⁴	1.6 × 10 ⁴	-	2.6 × 10 ⁴	1880	2.5	0.5	0.7	3.7

a. For BIF, binder is bitumen; for CIF, binder is cement.

b. Includes process and cooling tower makeup water.

TABLE 4.7.29. Effect of Immobilization of Intermediate-level Liquid Waste on Annual Requirements for Supplies, Utilities, and Manpower at the Fuel Reprocessing Plant Immobilization Facilities

Feed Option	Annual Supplies and Utilities					Water, (b) m ³	Processing Hours	Manpower, man-yr/yr			
	Drums	Binder, (a) kg	Electricity, kWh	Air, m ³	Steam, kg			Operators	Radiation Monitors	Maintenance	Total
<u>At Bitumen Immobilization Facility</u>											
ILLW	607	8.4 × 10 ⁴	1.6 × 10 ⁵	9.0 × 10 ³	3.4 × 10 ⁵	2.6 × 10 ²	1600	1.1	0.2	0.3	1.6
Total without ILLW	1921	2.7 × 10 ⁵	4.2 × 10 ⁵	2.5 × 10 ⁴	8.6 × 10 ⁵	6.4 × 10 ²	3590	2.6	0.4	0.6	3.7
Total with ILLW	2528	3.5 × 10 ⁵	5.3 × 10 ⁵	3.6 × 10 ⁴	1.2 × 10 ⁶	9.0 × 10 ²	5190	3.7	0.6	0.9	5.3
<u>At Cement Immobilization Facility</u>											
ILLW	1777	4.5 × 10 ⁵	3.0 × 10 ⁴	5.0 × 10 ³	-	8.4 × 10 ³	590	0.8	0.1	0.2	1.1
Total without ILLW	3803	6.5 × 10 ⁴	6.1 × 10 ⁴	1.1 × 10 ⁴	-	1.8 × 10 ⁴	1290	1.7	0.4	0.5	2.6
Total with ILLW	5585	1.1 × 10 ⁶	9.1 × 10 ⁴	1.6 × 10 ⁴	-	2.6 × 10 ⁴	1880	2.5	0.5	0.7	3.7

a. For BIF, binder is bitumen; for CIF, binder is cement.

b. Includes process and cooling tower makeup water.

TABLE 4.7.30. Characterization of Main Plant Bead Resins

Composition - 50 wt% polystyrene and
50 wt% water

Volume - 10 m³/yr

Density - 720 kg/m³

Activity, Ci/yr^(a)

⁹⁵Zr - 70

⁹⁵Nb - 150

¹⁰⁶Ru - 3800

¹²⁹I - 0.1

Other mixed fission products - 240

U - 0.1

Pu - 3700

Other mixed actinides - 3

a. Based on waste characterization
Table 3.3.33.

If these resins are immobilized in the BIF, the quantity of materials, utilities, and manpower would increase by a small amount, as shown in Table 4.7.31.

4.7.3.2 Technology Alternatives at Fuel Reprocessing Plant Immobilization Facilities

More than a dozen companies in the United States currently market radioactive waste immobilization processes. Four basic types of radioactive waste immobilization systems are available: cement with its variations, bitumen, urea-formaldehyde (U-F), and other organic polymer systems.

Most of the various cement systems that are commercially available use external, in-line cement-waste mixers.⁽⁴⁾ Each supplier offers variations in process equipment, immobilization agent, and additives. However the basic system--in which radioactive waste is mixed with water, if necessary, and possibly an additive--is repeated in each model.

The basic bitumen immobilization system commercially available in the U.S. is the screw extrusion system described in Section 4.7.1. Some variations in this system may be encountered. These variations include using a wiped film evaporator or a pot type of evaporation system where bitumen and wastes are mixed, water is evaporated, and the waste is fed to a drum. Also, the screw extruder-evaporator system may be used with polyethylene as the immobilization agent. Other variations may also be encountered in the bitumen immobilization support system.⁽¹⁾

The U-F systems and the organic polymer systems are discussed in detail in the sections to follow. As with the other technologies, although variations may be found in process equipment and immobilizing agents from system to system, the fundamentals of operation remain similar.

TABLE 4.7.31. Effect of Bead Resin Immobilization on Annual Requirements for Supplies, Utilities, and Manpower at the Bitumen Immobilization Facility

Feed Option	Drums	Supplies and Utilities				Processing Hours	Manpower, man-yr/yr		
		Bitumen, kg	Electricity, kWh	Air, m ³	Steam, kg	Water, (a) m ³	Operators	Radiation Monitors	Maintenance Total
Bead resin	42	3.6×10^3	3.0×10^3	1.8×10^2	6.8×10^3	1.1×10^1	0.03	0.01	0.01
Total without bead resin	2486	3.5×10^5	5.8×10^5	3.6×10^4	1.2×10^6	9.0×10^2	3.7	0.6	0.9
Total with bead resin	2528	3.5×10^5	5.8×10^5	3.6×10^4	1.2×10^6	9.1×10^2	3.7	0.6	0.9

a. Includes process and cooling tower makeup water.

All of these systems may be further modified by using various feed treatments. The treatment most often discussed is volume reduction, which is achieved by concentrating the liquid feed streams to reduce volume prior to immobilization. A bitumen system and an organic polymer system that include volume reduction as a fundamental part of process operation are commercially available. This option offers possible advantages in terms of operating capacity and potential cost reduction.

Other radioactive waste immobilization technologies have been proposed and are in various stages of development. Detailed discussions of some alternatives may be found in the literature.^(5,6)

Urea-Formaldehyde System. The immobilization of radioactive wastes in urea-formaldehyde (U-F) is a well-developed technology. Several companies in the United States market U-F radioactive waste immobilization systems. These U-F systems have been used extensively to immobilize radioactive wastes from various nuclear fuel cycle sources,⁽⁶⁾ thus providing many years of operational experience.

The U-F system is a polymeric process. There is no chemical reaction between U-F and the radioactive wastes. The polymer, after it is homogeneously mixed with radioactive waste, is made to form long-chain molecules of organic polymer that trap the radioactive waste within their structure.⁽⁵⁾ The chemical impetus to this immobilization process is an acidic catalyst such as H_3PO_4 , $NaHSO_4$, or H_2SO_4 ,⁽⁷⁾ which adjusts the pH to 1.5 ± 0.5 .

The mixing of the polymer and the radioactive waste is done in one of three types of mixers.⁽⁵⁾ These are the in-drum paddle mixer, the in-line static mixer, or the in-line mechanically driven mixer. For in-line mixing, after a good mix of the polymer and radioactive waste has been obtained, the mixture is delivered to a drum for filling. As filling takes place, the catalyst is added. The mixture will start to gel immediately. The gel times vary, depending on temperature and pH, but range from a few minutes to several hours.^(4,6) For the in-drum mixing, the catalyst, polymer, and radioactive waste are mixed together, a procedure usually used with problem feed streams.⁽⁵⁾

The immobilized U-F product is a homogeneous monolithic solid. It has a density slightly greater than water.⁽⁶⁾ Its leachability is roughly equivalent to that of cement.⁽⁸⁾ During immobilization, no detectable exothermic reaction occurs that might cause radionuclide volatilization.⁽⁵⁾

As mentioned previously, the U-F solidified product may be prepared in several mixing modes. One system incorporating the in-line static mixer is shown in Figure 4.7.18. The facility description of such a system would closely resemble either the CIF or BIF, with adjustments for particular equipment differences. The number of drums of U-F solidified product that would result would be roughly equivalent to that of the CIF. In addition, supplies, utilities, and manpower consumed would be similar to the CIF. The capital cost of the U-F system at the FRP would be in the range of the CIF and BIF estimates.

Other Organic Polymer Processes. Several U.S. companies are actively marketing additional polymeric processes for radioactive waste immobilization. Most of these processes are basically similar to the U-F systems in that radioactive waste is homogeneously mixed with an organic polymer. The mixture is fed to a drum, a catalyst is added, and the product solidifies by polymerization. Each vendor offers variations in polymers and catalysts, as well as in processing characteristics.

Several companies also offer polymeric radioactive waste immobilization systems. Most have as the final processing step the addition of a catalyst to a polymer that immobilizes the radioactive waste. The process flows for each of these systems is similar to that shown for the U-F system in Figure 4.7.18 except for the mixing system, which is tailored to the process. One major variation from that system description is an inert carrier process. Liquid radioactive wastes and sludges are injected into a high-temperature, silicone oil carrier fluid, where water is flashed from the mixture. The dried residue in the inert carrier is mixed with the polymer, separated from the carrier fluid, and fed to a drum along with a hardening catalyst.

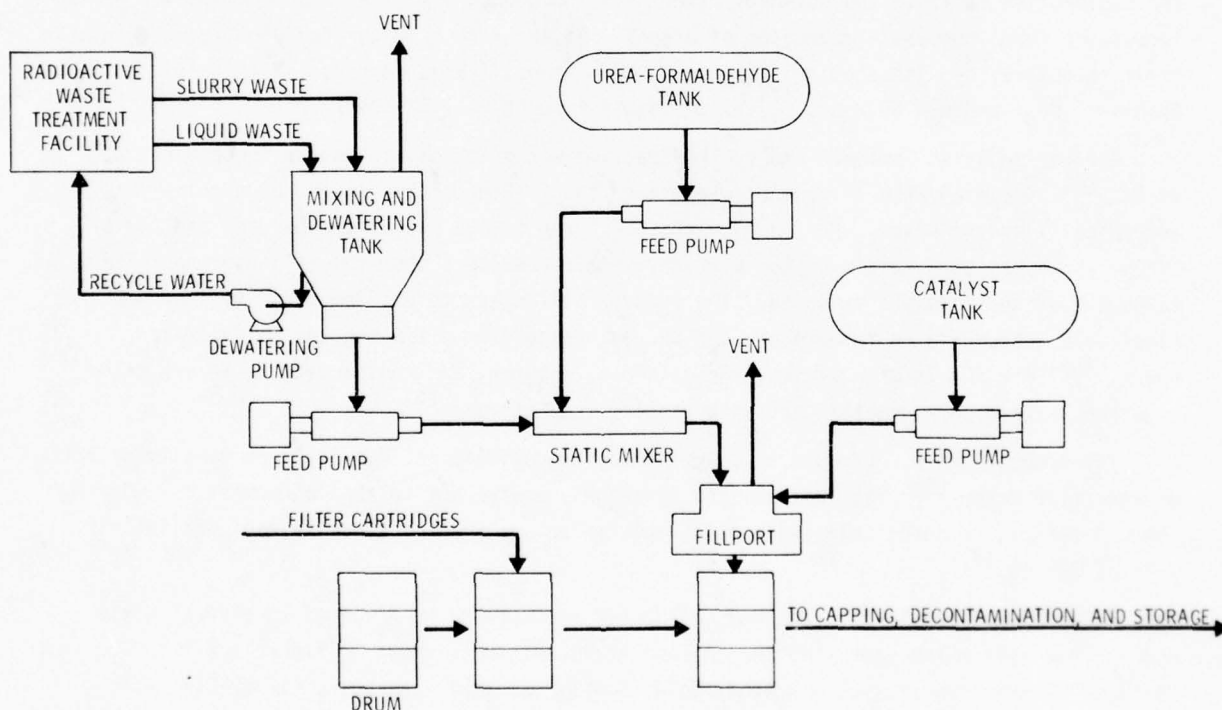


FIGURE 4.7.18. Flow Diagram for the Conceptual Fuel Reprocessing Plant Urea-Formaldehyde (U-F) System

The immobilized products from each of these processes are similar in form to the U-F immobilized product. Detailed information on product characteristics is limited because of the relative newness of the processes and the lack of commercial experience with them.

4.7.4 Bitumen Immobilization at a Mixed Oxide Fuel Fabrication Plant

As discussed in Section 4.7.1, bitumen immobilization of radioactive wastes is a well-demonstrated technology. The wastes to be immobilized at a mixed-oxide fuel fabrication plant (MOX FFP) are similar to FRP radioactive wastes in that they are largely nitrate salt solutions. In terms of radionuclide content, the MOX FFP wastes are dissimilar to FRP wastes but not enough so as to affect the process. The major difference is that the radiation dose rates of MOX FFP wastes are much lower and generally permit direct personnel contact, whereas FRP wastes require completely remote processing from a shielding standpoint. Processing of MOX FFP wastes is done remotely in the reference conceptual systems, however, because of a material containment necessity.

4.7.4.1 Bitumen Immobilization Process Alternatives at the Mixed Oxide Fuel Fabrication Plant

Process alternatives and criteria for reference process selection are the same as those discussed in Section 4.7.1.1.

4.7.4.2 Design Basis for the Bitumen Immobilization Facility at the Mixed Oxide Fuel Fabrication Plant

A single bitumen immobilization facility (BIF) is proposed for the reference 400-MTHM/yr MOX FFP. The BIF is designed for remote operation and contact maintenance. It is located in the radioactive waste treatment facility of the MOX FFP. Such items as the utility services and ventilation system are common with the MOX FFP. Only that portion of the building devoted to bitumen immobilization of radioactive wastes is described in this section.

The BIF is designed for an annual throughput of nearly 750 drums/yr of immobilized product containing over 100,000 Ci of actinide radioisotopes. The BIF is designed to store three months' worth of processed drums, or about 200 drums. The drum storage is designed to handle and load filled drums by the remote processing equipment.

4.7.4.3 Process for the Bitumen Immobilization Facility at the Mixed Oxide Fuel Fabrication Plant

The MOX FFP BIF is a one-step volume reduction and solidification process. It uses a screw extruder-evaporator for removing free water, mixing radioactive wastes with bitumen,

and homogeneously dispersing the wastes in a bitumen matrix. Activity levels for the wastes that must be processed are given in Table 4.7.33, along with waste volumes. A system flowsheet of the MOX FFP BIF is shown in Figure 4.7.19.

TABLE 4.7.33. Activity in Untreated Wastes for the Mixed Oxide Fuel Fabrication Plant Wet Waste Immobilization Facilities^(a)

Radionuclide	Ci/yr		Total
	Primary Wastes(b)	Secondary Wastes(c)	
²³⁹ Pu	57	172	230
²⁴¹ Pu	25,500	76,600	100,000
Other Pu	951	2,860	3,800
²⁴¹ Am	7,680	120	7,800
All other Actinides	0.7	2.2	2.9

a. Based on waste characterization Table 3.3.39 and secondary waste Table 3.5.2, assuming 400 MTHM MOX fuel fabrication 1 year after plutonium purification.

b. Untreated volume = 148 m³/yr.

c. Untreated volume = 138 m³/yr.

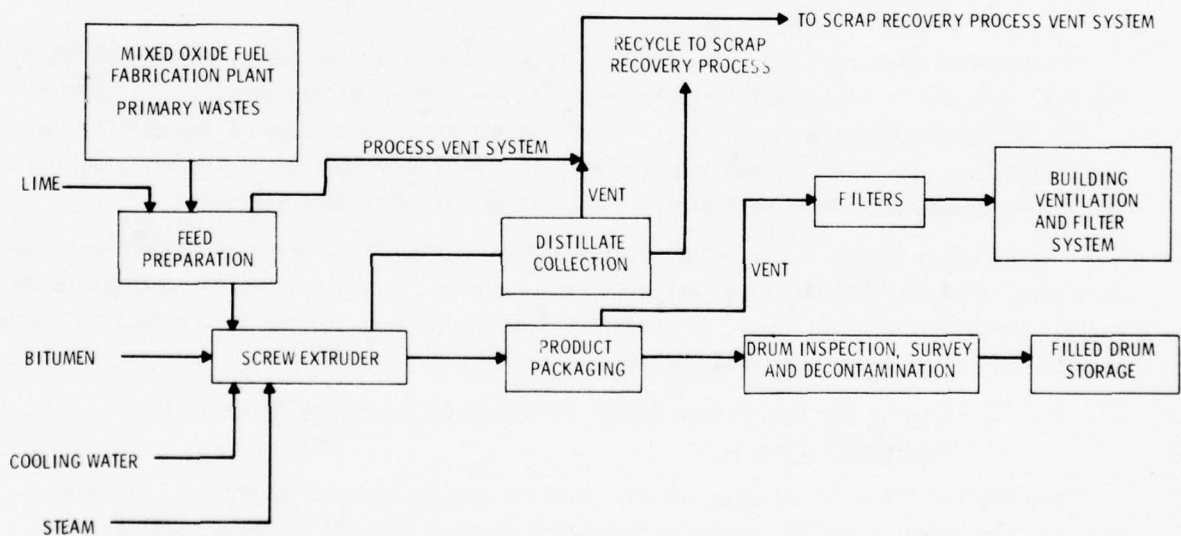


FIGURE 4.7.19. System Flowsheet for the Mixed Oxide Fuel Fabrication Plant Bitumen Immobilization Facility

Primary MOX liquid wastes that are to be immobilized in the bitumen system contain large quantities of ammonium nitrate. Thus the BIF provides for the removal of ammonia from the waste feed and for its recycle to the MOX FFP scrap recovery process. The policy of recovering ammonia and not solidifying it is based on the lack of experience and data demonstrating the safety of ammonium nitrate in bitumen. Other nitrates, including alkali and alkaline earth nitrates, have been solidified. Tests have shown a lowering of burning point of the waste-bitumen product when the nitrates or nitrites are in excess of 30 wt% of the product.⁽²⁾

As Figure 4.7.19 shows, the major components of the system are feed preparation, waste extrusion and evaporation, product packaging, inspection, survey, decontamination, and interim storage. Because of the low radiation levels of the MOX FFP wastes, operations on the filled waste drums such as inspection, surveying, decontamination, and handling need not be done remotely.

In the BIF, the primary waste stream is made alkaline with hydrated lime and fed to the extruder-evaporator where it is mixed with bitumen. Water and ammonia are driven off the waste-bitumen mixture in the extruder, condensed, passed through an oil filter, and recycled to the MOX FFP scrap recovery process. The waste-bitumen mixture is extruded into DOT Specification 17C, 55-gal removeable head steel drums. The drummed waste is then inspected, surveyed, decontaminated if necessary, and stored. A detailed description of the operation of the BIF may be found in Section 4.7.1.3.

A process flow diagram is shown in Figure 4.7.20 and the material flows are shown in Table 4.7.34. The waste-bitumen product mixture is characterized in Table 4.7.35. There are

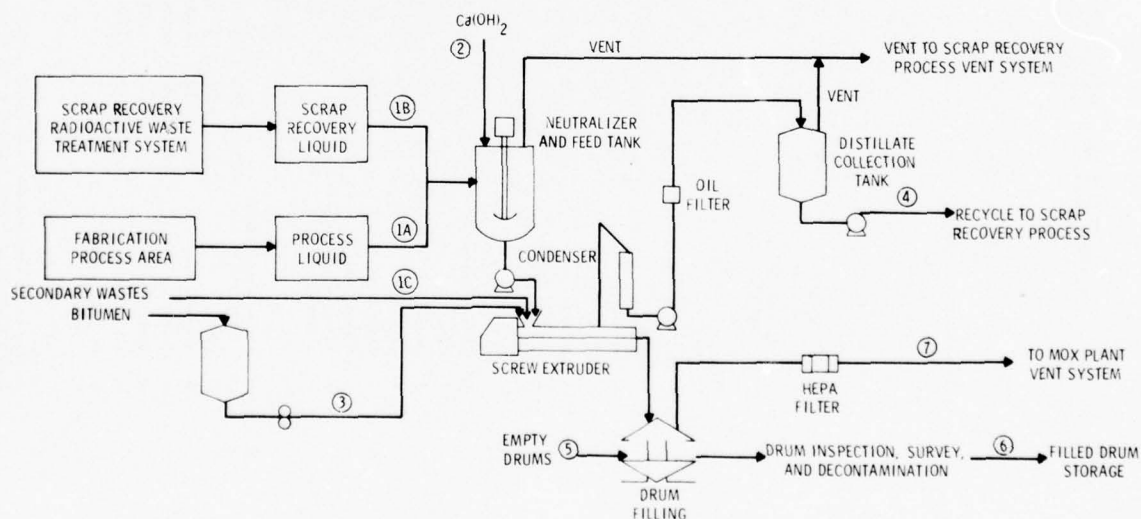


FIGURE 4.7.20. Process Flow Diagram for the Mixed Oxide Fuel Fabrication Plant Bitumen Immobilization Facility

TABLE 4.7.34. Material Balance for the Mixed Oxide Fuel Fabrication Plant Bitumen Immobilization Facility

Stream Number	Stream Material Description	Volume m ³ /yr	Density kg/m ³	Mass kg/yr	Temperature °C	Number of Drums/yr	Radioactivity (e)				
							Americium	Plutonium	Uranium	All Other Actinides	
PRIMARY WASTE											
1A	Process Solution (b)	8	1,200	9,600	Ambient		170	3,930	5 x 10 ⁻⁴	0.023	0.120
1B	Scrap Recovery Solution (b)	140	1,100	154,000	Ambient		1,710	39,300	0.983	0.227	0.388
2	Line	4.9	1,200	5,900	Ambient		0	0	0	0	0
3	Bitumen	73	1,050	76,600	120		0	0	0	0	0
4	Distillate	135	990	134,000	40		0.3	7.2	2 x 10 ⁻⁴	4 x 10 ⁻⁵	6 x 10 ⁻⁵
5	Empty Drums	99	115	11,400	Ambient	456	0	0	0	0	0
6	Filled Drums	99	1,230	121,000	Ambient	456	1,880	43,200	0.984	0.249	0.508
7	Filling Station Vent (d)				Ambient		2 x 10 ⁻⁷	4 x 10 ⁻⁶	1 x 10 ⁻¹⁰	2 x 10 ⁻¹¹	5 x 10 ⁻¹¹
SECONDARY WASTE - MISCELLANEOUS SOLUTIONS											
1C	Miscellaneous Solutions (c)	1.6	1,200	1,900	Ambient		510	11,500	0.001	0.068	0.045
2	Line	0	1,200	0	Ambient		0	0	0	0	0
3	Bitumen	0.5	1,050	490	120		0	0	0	0	0
4	Distillate	1.4	1,000	1,400	40		0.09	1.9	2 x 10 ⁻⁷	1 x 10 ⁻⁵	8 x 10 ⁻⁵
5	Empty Drums	0.9	115	100	Ambient	4	0	0	0	0	0
6	Filled Drums	0.9	1,210	1,090	Ambient	4	510	11,500	0.001	0.068	0.045
7	Filling Station Vent (d)				Ambient		5 x 10 ⁻⁸	1 x 10 ⁻⁶	1 x 10 ⁻¹³	7 x 10 ⁻¹²	5 x 10 ⁻¹²
SECONDARY WASTE - INCINERATOR ASH											
1C	Incinerator Ash (c)	8	240	1,920	Ambient		115,000	72,500	0.015	0.682	0.446
2	Line	0	1,200	0	Ambient		0	0	0	0	0
3	Bitumen	1.9	1,050	1,990	120		0	0	0	0	0
4	Distillate	0	1,000	0	40		0	0	0	0	0
5	Empty Drums	3.5	115	400	Ambient	16	0	0	0	0	0
6	Filled Drums	3.5	1,230	4,310	Ambient	16	115,000	72,500	0.015	0.682	0.446
7	Filling Station Vent (d)				Ambient		1 x 10 ⁻⁵	7 x 10 ⁻⁶	2 x 10 ⁻¹²	7 x 10 ⁻¹¹	4 x 10 ⁻¹¹
SECONDARY WASTE - INCINERATOR SCRUBBER SOLUTION											
1C	Incinerator Scrubber Solution (c)	127	1,020	130,000	Ambient		5.1	120	1 x 10 ⁻⁵	7 x 10 ⁻⁴	4 x 10 ⁻⁴
2	Line	0	1,200	0	Ambient		0	0	0	0	0
3	Bitumen	6.3	1,050	6,590	120		0	0	0	0	0
4	Distillate	124	1,000	124,000	40		9 x 10 ⁻⁴	2 x 10 ⁻²	2 x 10 ⁻⁹	1 x 10 ⁻⁷	7 x 10 ⁻⁸
5	Empty Drums	12	115	1,350	Ambient	54	0	0	0	0	0
6	Filled Drums	12	1,160	13,900	Ambient	54	5.1	120	1 x 10 ⁻⁵	7 x 10 ⁻⁴	4 x 10 ⁻⁴
7	Filling Station Vent (d)				Ambient		5 x 10 ⁻⁹	1 x 10 ⁻⁸	1 x 10 ⁻¹⁵	7 x 10 ⁻¹⁴	4 x 10 ⁻¹⁴

a. Fraction of input radioactivity (Table 4.7.33).
 b. Characterized in Primary Waste Table 3.3.39.
 c. Characterized in Secondary Waste Table 3.5.2.
 d. 10 m³/hr of air.

two product streams for the MOX-FFP BIF, as shown in Table 4.7.35. These are composites of the primary waste and miscellaneous secondary solutions, and the incinerator residues. Unlike the FRP, the product streams have no differences in surface dose rate categories; thus the composite waste stream splits have been assumed.

TABLE 4.7.35. Treated Waste from MOX-FFP Bitumen Immobilization

Waste Type and Surface Dose Rate Class	Volume ^(a) m ³ /yr	Density kg/m ³	Volume Ratio Treated/Untreated	Drums Per Year	Radioactivity Factors ^(b)
Bitumenized Wet and Particulate Wastes					
<0.2 R/hr (2×10^{-4} R/hr)	97	1,230	0.65	460	$^{241}\text{Am} = 0.985$ Other = 0.318
Bitumenized Incinerator Ash and Scrubber Solution					
<0.2 R/hr (0.001 R/hr)	15	1,230	0.11	70	$^{241}\text{Am} = 0.015$ Other = 0.682

a. Treated volume based on container volume.

b. Fraction of facility input (Table 4.7.33).

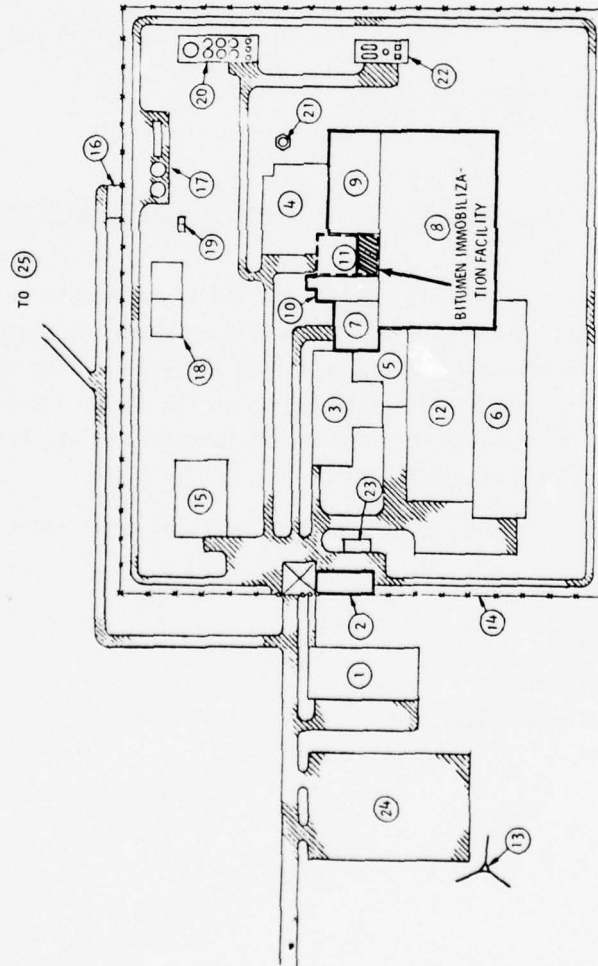
4.7.4.4 Description of the Bitumen Immobilization Facility at the Mixed Oxide Fuel Fabrication Plant

The conceptual BIF is contained within the MOX FFP and is assumed to be a Category I structure. A plot plan indicating the location of the BIF is shown in Figure 4.7.21. A conceptual layout of the facility is shown in Figures 4.7.22 and 4.7.23. The total floor space of the BIF is approximately 450 m² (4800 ft²), including about 100 m² for storing three months' production of filled drums. As shown in the layout, all functions of the BIF, including filling and storage, are performed within the facility.

Major Process Equipment. - The MOX FFP BIF has the following eight major system components:

- waste feed system
- bitumen feed system
- screw extruder-evaporator
- filling and capping stations
- inspection and decontamination stations
- container transfer cart
- bridge cranes
- control module.

- 1 GENERAL ADMINISTRATION
- 2 MAIN SECURITY STATION
- 3 PERSONNEL CONTROL
- 4 UTILITIES & SERVICES
- 5 UO_2 RECEIVING & PREPARATION
- 6 TUBE/HARDWARE RECEIVING & PREPARATION
- 7 PuO_2 RECEIVING & PREPARATION
- 8 PELLET/ROD PRODUCTION
- 9 PROCESS SUPPORT
- 10 SMM REWORK & RECOVERY
- 11 PRODUCTION MAINTENANCE & WASTE
- 12 ROD FINISH & SHIPPING
- 13 METEOROLOGICAL TOWER
- 14 PROTECTED AREA SECURITY FENCE
- 15 WAREHOUSE/SHOP
- 16 ELECTRICAL SUBSTATION
- 17 FIREWATER TANKS & PUMPS
- 18 IMPOUNDMENT PONDS
- 19 COOLING TOWER
- 20 TANK FARM
- 21 PLANT STACK
- 22 PRODUCTION GAS FACILITY
- 23 EMERGENCY VEHICLES
- 24 PARKING
- 25 SEWAGE TREATMENT



0 50 100 FT
GRAPHIC

FIGURE 4.7.21. Approximate Location of the Bitumen Immobilization Facility at the Mixed Oxide Fuel Fabrication Plant

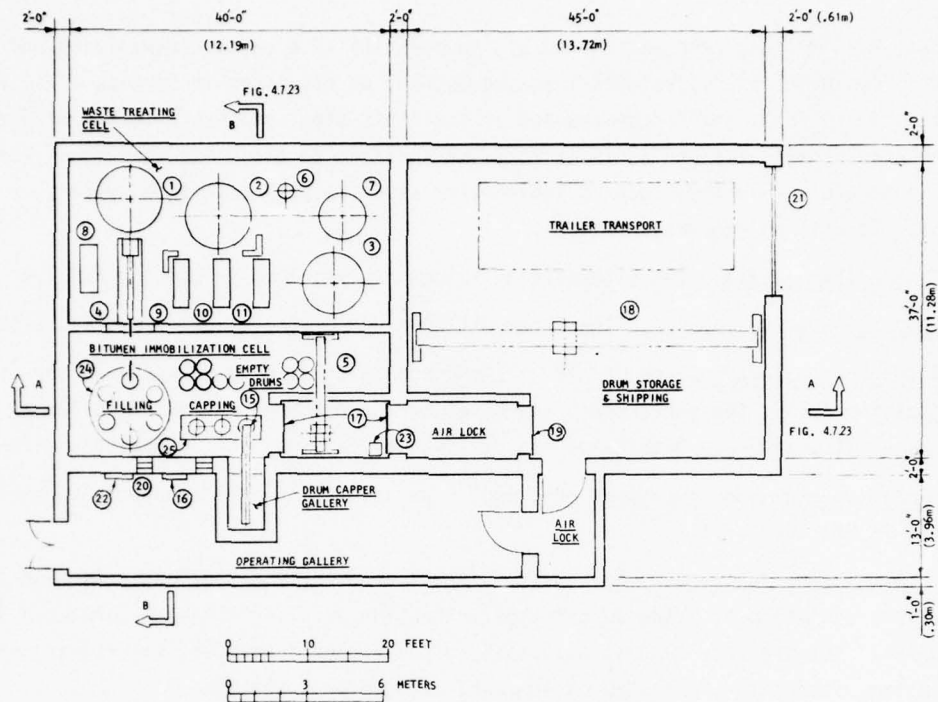


FIGURE 4.7.22. Mixed Oxide Fuel Fabrication Plant Bitumen Immobilization Facility Plan

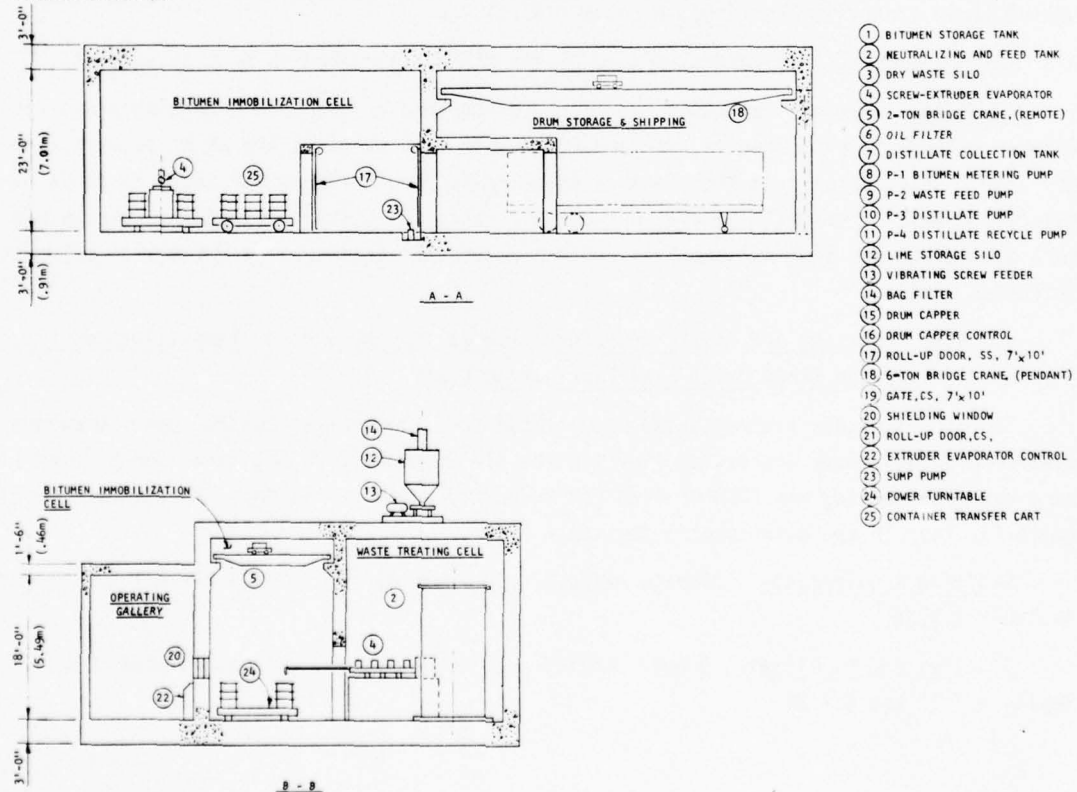


FIGURE 4.7.23. Mixed Oxide Fuel Fabrication Plant Bitumen Immobilization Facility Plan, Sections A-A and B-B

Waste Feed System. The waste feed system consists of a waste neutralizing and feed tank, the waste feed pump, and associated instrumentation, as discussed in Section 4.7.1.4. The neutralizing and feed tank is constructed of stainless steel and has a volume of 3 m^3 . It is equipped with an agitator and an inlet for lime addition to the waste solution. For the immobilization of dry solids such as incinerator ashes, a dry waste feed system, as shown in Figure 4.7.8, will be required.

Bitumen feed system. The bitumen feed system is described in Section 4.7.1.4.

Screw extruder-evaporator. The screw extruder-evaporator is described in Section 4.7.1.4.

Filling and capping stations. The filling operation is done remotely in the bitumen immobilization cell. The empty drums are moved to a turntable that holds six drums and that uses a multiple fill sequence. Details of the filling and capping stations are given in Section 4.7.1

Inspection and decontamination stations. The inspection and decontamination stations are described in Section 4.7.1.4.

Container transfer cart. The container transfer cart is described in Section 4.7.1.4. However, one deviation from the description in Section 4.7.1.4 is that a turntable is used in the MOX FFP. The transfer cart is used to move the filled drums from the filling station through drum capping, inspection, decontamination, and into interim storage.

Bridge crane. As shown in Figure 4.7.23, two bridge cranes are used in the BIF. The use of these cranes is described in Section 4.7.1.4.

Control Module. The control module of the BIF is described in Section 4.7.1.4.

Shielding. Minimal radiation shielding is required at the BIF. The unshielded waste-bitumen mixture is estimated to have a surface dose rate of about 500 mR/hr primarily because of ^{241}Am . Attenuation from the 16-gauge steel drums should reduce this rate to about 20 mR/hr.⁽⁹⁾ All filled waste drums will have a surface dose rate of less than 50 mR/hr. Process equipment, such as the storage tank and extruder, will have greater attenuation factors to shield the untreated wastes.

4.7.4.5 Operating and Maintenance Requirements for the Bitumen Immobilization Facility at the Mixed Oxide Fuel Fabrication Plant

The BIF is highly automated and is operated from the central control panel previously described. The annual processing time for the BIF is about 2100 hr, with 1200 hr used for primary waste processing and 1050 hr used for secondary waste processing. Maintenance requirements for the BIF are described in Section 4.7.1.5.

Staffing Requirements. Average manpower requirements for the MOX FFP BIF are summarized in Table 4.7.36.

Supplies and Utilities. Annual utility and supply requirements are summarized in Tables 4.7.37 and 4.7.38.

TABLE 4.7.36. Staffing Requirements for the Mixed Oxide Fuel Fabrication Plant Bitumen Immobilization Facility

Waste Processed	Manpower Requirements, man-yr/yr		
	Operators	Radiation Monitor	Maintenance Craftsmen
Primary wastes	0.8	0.1	0.2
Miscellaneous secondary solutions	0.01	0.001	0.002
Incinerator ash	0.01	0.001	0.002
Incinerator blowdown	0.8	0.1	0.2
Facility total	1.6	0.2	0.5

TABLE 4.7.37. Supply Requirements for the Mixed Oxide Fuel Fabrication Plant Bitumen Immobilization Facility

Waste Processed	Annual Supply Requirements		
	Drums (a)	Bitumen, (b) kg	Lime, (c) kg
Primary waste	456	76,000	5,900
Miscellaneous secondary solution	4	490	0
Incinerator ash	16	1,990	0
Incinerator blowdown	54	6,590	0
Facility total	530	85,100	5,900

a. DOT Specification 17C, 55-gal drums.

b. Bitumen is steep roofing type and has the following characteristics:

Softening point	88 to 93°C
Flashing point	290°C
Penetration at 25°C	20 to 30 mm
Density	1000 kg/m ³
Solubility in CCl ₄	99.0%

c. Ca(OH)₂

Hazardous Materials. No unduly hazardous materials are involved in the operation of the MOX FFP BIF, as discussed in Section 4.7.1.5.

4.7.4.6 Secondary Radioactive Wastes for the Bitumen Immobilization Facility at the Mixed Oxide Fuel Fabrication Plant

Secondary radioactive wastes generated at the MOX FFP BIF are summarized in Table 4.7.39.

TABLE 4.7.38. Utility Requirements for the Mixed Oxide Fuel Fabrication Plant Bitumen Immobilization Facility

Waste Processed	Annual Utility Requirements			
	Electricity, kWh(a)	Air, m ³ (b)	Steam, kg(c)	Water Consumed, m ³ (d)
Primary waste	1.2×10^5	7.2×10^3	3.4×10^5	4.3×10^2
Miscellaneous secondary solutions	1.3×10^3	7.0×10^1	3.5×10^3	4.5
Incinerator ash	4.7×10^2	3.0×10^1	1.4×10^3	1.1
Incinerator blowdown	1.0×10^5	6.2×10^3	2.9×10^5	3.8×10^2
Facility total	2.2×10^5	1.4×10^4	6.3×10^5	8.2×10^2

a. Use rate of 100 kW.

b. 80 to 100 psig, use rate of 6 m³/hr.

c. 217°C at 300 psig, use rate of 280 kg/hr.

d. Use rate of 0.4 m³/hr.

TABLE 4.7.39. Secondary Radioactive Wastes for the Mixed Oxide Fuel Fabrication Plant Bitumen Immobilization Facility

Waste Category	Volume, m ³ /yr	Radioactivity Factor(a)
Compactable and combustible wastes		
HEPA filter	1.1	10^{-6}
General trash	3.3	10^{-6}
Concentrated liquids, wet wastes and particulate solids	0.05	10^{-3}
Solid noncompactable, noncombustible wastes	0.8	2×10^{-6}

a. Fraction of input activity (Table 4.7.33) in secondary waste.

4.7.4.7 Emissions from the Bitumen Immobilization Facility at the Mixed Oxide Fuel Fabrication Plant

No liquid process effluents will be released to the environment. Condensed process steam and cooling water are recycled within the MOX FFP.

Vessel and process off-gas vents, including the vented hood at the filling station, discharge about 210 m³/hr into the facility ventilation system. The building ventilation system discharges a total of about 12,000 m³/hr (equivalent to six solidification-storage facility volume changes per hour) to the MOX FFP stack.

Airborne radioactive emissions from the BIF may pass through two different pathways, as described in Section 4.7.1.7. Airborne emissions originating from process vents and passing through the BIF HEPA filter release 1×10^{-10} of the BIF feed radionuclides. This release is then circulated to the MOX FFP atmospheric protection system.

Airborne radioactive emissions from the BIF originating in the concentration of secondary liquid wastes will come through the MOX FFP general purpose concentrator and released through excess water vaporizer. Radionuclides released by this pathway are 3×10^{-12} of the BIF feed radionuclides. They are released directly to the MOX FFP stack.

An estimate of the integrated release due to minor accidents, Section 4.7.4.9, for this facility is included in Table 4.7.40. It was developed by weighing the minor accident releases by their expected frequencies and summing the quantities for all identified minor accidents. In addition, a contingency was included in the integrated release to account for unidentified minor accidents and to compensate for the uncertainty in expected frequency information. Estimated integrated annual releases due to minor accidents for this technology are shown in Table 4.7.40.

Radioactive releases resulting from operations in the BIF are in the form of particulate aerosols composed of oxides and salts, both soluble and insoluble. No nonradioactive toxic emissions from the MOX FFP BIF have been identified.

For primary waste immobilization, heat releases from operation of the BIF are about 2.5×10^2 MW-hr/yr (8.3×10^8 BTU/yr) with about half of this amount discharged in condensate cooling water and about half discharged to the air. In secondary waste immobilization, heat releases will be 120 kWh (4.1×10^5 BTU) per hour of operation plus .74 MW-hr (2.5×10^6 BTU) per m^3 of water contained in the waste, the heat being dissipated as in primary waste immobilization. Thus, the total heat release for secondary waste immobilization will be about 2.3×10^2 MW-hr/yr (8.0×10^8 BTU/yr).

Major emissions from the MOX BIF are shown in Table 4.7.40.

TABLE 4.7.40. Emissions from the Mixed Oxide Fuel Fabrication Plant Bitumen Immobilization Facility

Emission	Description	Annual Quantity	Radioactivity Release Factor to Atmosphere ^(a)
Gaseous	Process off-gas	Air $2.2 \times 10^4 m^3$	A11 1×10^{-17}
	Vaporized excess water	H ₂ O $4.6 \times 10^5 kg$	A11 3×10^{-12}
	Minor accident integrated annual release		A11 7×10^{-18}
Cooling tower water	Evaporated (T = 38°C)	$7.0 \times 10^5 kg$	
	Drift (T = 38°C)	$3.4 \times 10^3 kg$	
	Blowdown (T = 27°C)	$1.2 \times 10^5 kg$	
Other	Heat	4.7×10^2 MW-hr (1.6×10^9 BTU)	

a. Fraction of input activity (Table 4.7.33) released to atmosphere. Includes DF from main plant APS where applicable. Released over 90 days/year.

4.7.4.8 Decommissioning Considerations for the Bitumen Immobilization Facility at the Mixed Oxide Fuel Fabrication Plant

The BIF is designed to last 30 years. The equipment is readily flushable, making it possible to decontaminate both equipment and facility to 10 mrem/hr for decommissioning.

4.7.4.9 Postulated Accidents for the Bitumen Immobilization Facility at the Mixed Oxide Fuel Fabrication Plant

Postulated accidents for the BIF are discussed in Section 4.7.1.9. The accidents selected as worst case in Section 4.7.1.9 have radionuclide source terms as specified for the FRP BIF. Three main differences exist for the MOX FFP BIF. First, the radionuclide spectrum released in the FRP BIF postulated accidents consists of mixed activation products, fission products, and actinides, whereas only actinides are available for release at the MOX FFP. Second, the quantity of radionuclides released from the FRP is greater than for the MOX FFP. Third, only three drums at the FRP BIF may catch fire, while six are available in the MOX FFP BIF. However, the activity released from the FRP waste is greater, even with this consideration.

4.7.4.10 Costs for the Bitumen Immobilization Facility at the Mixed Oxide Fuel Fabrication Plant

Estimates have been made, in mid-1976 dollars, of capital, operating and levelized unit costs. A complete description of the cost estimate bases, assumptions and definitions is given in Section 3.8.

Capital Costs. The capital construction cost estimate for the BIF is summarized in Table 4.7.41.

Operating Costs. Costs of direct labor, materials, and utilities are based on requirements given in Tables 4.7.37, 4.7.38 and 4.7.39. Costs of process materials for bitumen immobilization at the MOX FFP are \$0.07 per kg of CaO, at \$0.105 per kg of bitumen, and \$20 each for DOT Specification 17C drums. Maintenance materials costs are estimated at 3% of major equipment Table 4.7.42 summarizes the operating costs.

Levelized Unit Cost. The levelized unit cost, including levelized capital and operating costs, is shown in Table 4.7.43. The unit cost calculation assumes private ownership of the facilities.

4.7.4.11 Construction Requirements for the Bitumen Immobilization Facility at the Mixed Oxide Fuel Fabrication Plant

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating the impact of construction activities.

4.7.63

TABLE 4.7.41. Capital Cost Estimate for the Mixed Oxide Fuel Fabrication Plant Bitumen Immobilization Facility

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		10	1,800	200	2,000
Buildings and structures		80	500	1,100	1,600
Bulk materials		80	1,500	900	2,400
Site improvements					
Subtotal of direct site construction costs		170	3,800	2,200	6,000
Indirect site construction costs	40	30	800	1,100	1,900
Total field cost	40	200	4,600	3,300	7,900
Architect-engineer services					1,600
Subtotal					9,500
Owner's cost					2,500
Total facility cost					12,000
Estimate accuracy range					±25%

TABLE 4.7.42. Operating Cost Estimate for the Mixed Oxide Fuel Fabrication Plant Bitumen Immobilization Facility

Cost Element	Annual Costs, \$1000s
Direct labor	31
Process materials	28
Utilities	6
Maintenance materials	60
Overhead	70
Miscellaneous	35
Total	230 +50% -25%

TABLE 4.7.43. Levelized Unit Cost Estimate for the Mixed Oxide Fuel Fabrication Plant Bitumen Immobilization Facility

Cost Element	Unit Cost, \$/kg HM(a)
Levelized capital charge	7.50
Levelized operating charge	0.50
Levelized total unit cost	8.00 ±35%

a. Dollars per kg HM MOX fuel. To convert to \$/kg HM reprocessed, divide by 5.

Project Schedules and Construction Manpower. The schedule for engineering, procurement, and construction of the BIF is an integral factor in the overall schedule for the construction of the MOX FFP. The field labor force estimated for the construction of the BIF is tabulated as follows:

	Man-hours, 1000s
Manual field labor	200
Nonmanual field labor	40
Total field labor	240

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials, and services provided at the site of the MOX FFP; offsite costs are those for all services provided, equipment fabricated and/or assembled, and material purchased elsewhere. The distribution of total costs in these categories is as follows:

	Costs, \$1000s
Onsite	4,000
Offsite	8,000
Total	12,000

Site Requirements. The BIF requires about 450 m^2 (4800 ft^2) within the MOX FFP site.

Water. Water used during the construction period is approximately $3,000 \text{ m}^3$ ($0.8 \times 10^6 \text{ gal}$).

Construction Materials. Materials committed to facility construction are:

Concrete	$1,500 \text{ m}^3$	(2,000 yd^3)
Steel	360 MT	(400 tons)
Copper	5 MT	(6 tons)
Lumber	93 m^3	(40 MFBM)

Energy. Energy resources used during construction are:

Propane	26 m^3	(7,000 gal)
Diesel fuel	265 m^3	(70,000 gal)
Gasoline	190 m^3	(50,000 gal)
Electricity		
Peak demand	300 kW	
Total consumption	200,000 kWh	

Transportation Requirements. No separate transportation requirements for the BIF have been identified beyond those for the MOX FFP.

4.7.4.12 Effects of Fuel Cycle Options

The BIF would not be required for the once-through fuel cycle or for the uranium-recycle-only fuel cycle. The facility and process described here apply only to the uranium-plutonium recycle fuel cycle.

4.7.5 Cement Immobilization at a Mixed Oxide Fuel Fabrication Plant

As discussed in Section 4.7.2, cementation of radioactive wastes has been well demonstrated. In processing MOX FFP wastes, which are characterized by their high ammonia content and radioactivity composed entirely of actinides, an extension of proven technology is made. However, the wastes are similar to FRP wastes, provided the ammonia is removed. Other differences between MOX FFP and FRP waste processing are discussed in Section 4.7.4.

4.7.5.1 Cementation Process Alternatives at the Mixed Oxide Fuel Fabrication Plant

A waste-cement product may be prepared in a batch or a continuous mode. The product may be formed by mixing outside of the disposal container or within the container. Basic features of several systems are described in ERDA 76-43⁽⁴⁾ and are discussed briefly in Section 4.7.2.1 of this report.

4.7.5.2 Facility Design Basis for the Cement Immobilization Facility at the Mixed Oxide Fuel Fabrication Plant

The conceptual cement immobilization facility (CIF) for the MOX FFP incorporates features characteristic of several operating facilities but is not identical to any. The selected facility provides for removal of ammonia from primary aqueous wastes prior to cementation to avoid possible postcementation pressurization of sealed containers. Such removal by evaporation leads to a reusable aqueous ammonia stream and to reduced disposal costs by volume reduction. Other design requirements are similar to those discussed in Section 4.7.4.2.

4.7.5.3 Process for the Cement Immobilization Facility at the Mixed Oxide Fuel Fabrication Plant

The CIF is contained within the MOX FFP. Primary liquid wastes from fuel fabrication processing and scrap recovery operations are received from the MOX FFP by transfer piping into collection tanks. Scrap recovery solutions are first treated with hydrated lime to achieve a solution with a pH of 10 and are then evaporated to form a concentrated, ammonia-free product. The condensed, ammoniated evaporator overheads are routed to the scrap recovery system (not part of the CIF) for reuse. The concentrate is blended with the process solutions and metered into DOT Specification 17C, 55-gal drums. Dry cement is added to the drum and an agitator is lowered into the drum to mix the blend. The agitator is removed and the drum is capped, sealed, surveyed, decontaminated if necessary, and sent to storage to await subsequent disposal. This description is shown systematically in Figure 4.7.24. Activity levels and volumes for the wastes that the CIF must process are given earlier in Table 4.7.33.

Waste solutions, incinerator ash, incinerator off-gas, scrub solution, and cement mixtures that optimize product performance are summarized in Table 4.7.44. The CIF process flow

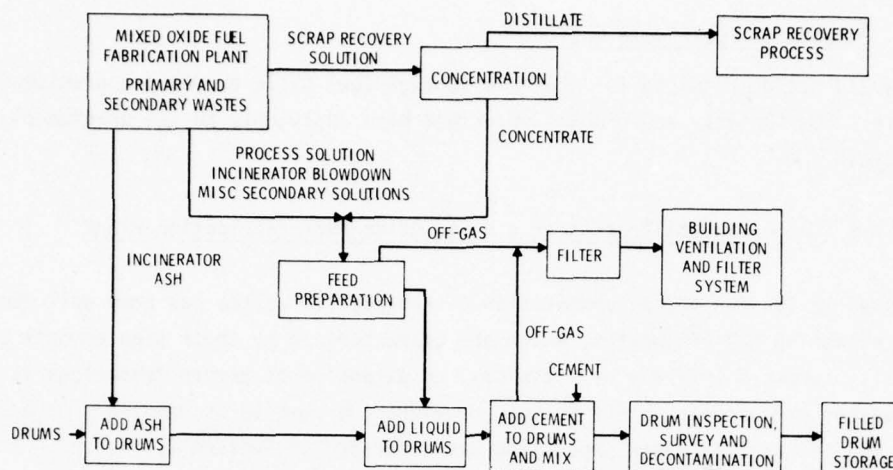


FIGURE 4.7.24. System Flow Diagram for the Mixed Oxide Fuel Fabrication Plant Cement Immobilization Facility

TABLE 4.7.44. Waste-Cement Formulations

Waste Type	Wt% Dry Solid	Wt% Liquid	Wt% Cement	Product Density, kg/m ³ (a)
Scrap recovery solution (with lime)		40	60	2050
Process solution		34	66	2020
Miscellaneous solution (25 wt% solids, 75 wt% water)		40	60	1900
Incinerator ashes	15	40 ^(b)	45	1640
Incinerator blowdown		36	60	1800

a. Product density without canister.

b. Incinerator blowdown.

diagram and material balance for primary and secondary wastes are shown in Figure 4.7.25 and Table 4.7.45, respectively. Solidified product characteristics are shown in Table 4.7.46. As shown in Table 4.7.46, two composited waste streams exist at the MOX FFP CIF, the primary wastes water the miscellaneous secondary solutions and the incinerator residues. There are no overriding product dose rate criteria which would imply different compositing scheme; thus the product stream mixes have been assumed.

Various secondary wastes are immobilized in the CIF. Miscellaneous concentrated solutions are immobilized through the same route as the process liquid waste. If incineration of compactable trash and combustible waste is selected, incinerator ashes and incinerator off-gas scrub solution (blowdown) will need to be immobilized. A system flowsheet for incinerator residue immobilization is included in Figure 4.7.25. As shown, the blowdown is collected

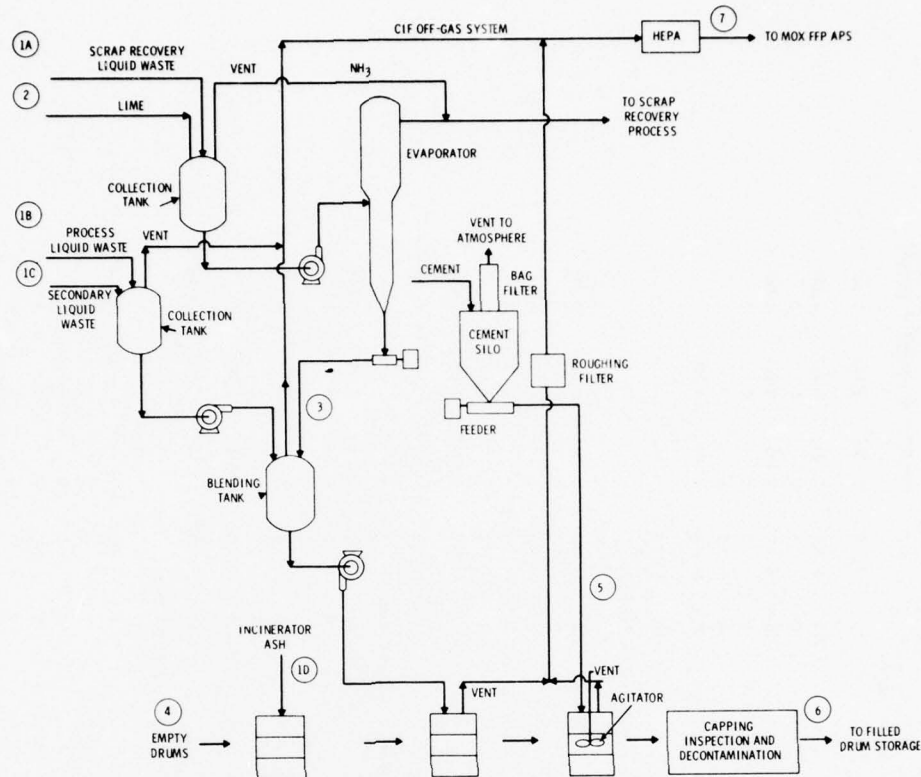


FIGURE 4.7.25. Process Flow Diagram for the Mixed Oxide Fuel Fabrication Plant Cement Immobilization Facility

in a storage tank prior to immobilization. The ashes are preweighed into 55-gal drums to assure the proper mix ratios shown in Table 4.7.44. The blowdown is then added to the ash or to an empty drum if no ash is available for immobilization. The drums are sent to the filling station; the remainder of the process continues as previously described in this section. The process flow additions from immobilization of secondary wastes are summarized in Table 4.7.45.

As shown in Table 4.7.45, incinerator off-gas scrub solution (blowdown) represents a major portion of the secondary wastes processed in this facility. The solution is projected to be quite dilute. An appreciable volume savings could be obtained by concentrating the blowdown in the facility concentrator. This option would necessitate a separate condenser and distillate collection system to avoid potential contamination of the ammonia distillate. In addition, special materials would be required in the construction of the concentrator to avoid severe corrosion attributable to the concentrated NaCl blowdown solution. The reference facility does not include a separate concentrator for this purpose.

4.7.5.4 Description of the Cement Immobilization Facility at the Mixed Oxide Fuel Fabrication Plant

The CIF is contained within the MOX FFP and is a Category I structure. Figure 4.7.26 shows a plot plan of the conceptual MOX FFP with the location of the CIF. A conceptual layout of the facility is shown in Figures 4.7.27, 4.7.28, and 4.7.29. The total floor space of the facility is about 520 m² (5600 ft²).

TABLE 4.7.45. Material Balance for the Mixed Oxide Fuel Fabrication Plant Cement Immobilization Facility

Stream Number	Stream Material Description	Volume m ³ /yr	Density kg/m ³	Mass kg/yr	Temperature °C	Number of Drums/yr	Radioactivity (a)			
							Americium	Plutonium	Uranium g/yr	All Other Actinides
1B	Process Solution (b)	8	1,200	9,600	Ambient					
1A	Scrap Recovery Solution (b)	140	1,100	154,000	Ambient					
2	Lime	5.2	1,200	6,300	Ambient					
3	Concentrate	57	1,360	77,980	Ambient					
4	Empty Drums	124	115	14,300	Ambient	570				
5	Cement	90	1,500	135,000	Ambient					
6	Filled Drums	124	1,910	237,000	Ambient	570				
7	Filling Station Vent (d)				Ambient					
SECONDARY WASTE - MISCELLANEOUS SOLUTIONS										
1C	Miscellaneous Solutions (c)	1.6	1,200	1,900	Ambient					
2	Lime	0	1,200	0	Ambient					
3	Concentrate	0	1,360	0	Ambient					
4	Empty Drums	3.0	115	350	Ambient	14				
5	Cement	1.9	1,500	2,800	Ambient					
6	Filled Drums	3.0	1,680	5,050	Ambient	14				
7	Filling Station Vent (c)				Ambient					
SECONDARY WASTE - INCINERATOR ASH										
1D	Incinerator Ash (c)	8	240	1,920	Ambient					
2	Lime	0	1,200	0	Ambient					
3	Concentrate	0	1,360	0	Ambient					
4	Empty Drums	9.3	115	1,080	Ambient	43				
5	Cement	3.8	1,500	5,760	Ambient					
6	Filled Drums	9.3	950	8,760	Ambient	43				
7	Filling Station Vent (d)				Ambient					
SECONDARY WASTE - INCINERATOR SCRUBBER										
1C	Incinerator Scrubber Solution (c)	127	1,020	130,000	Ambient					
2	Lime	0	1,200	0	Ambient					
3	Concentrate	0	1,360	0	Ambient					
4	Empty Drums	224	115	25,700	Ambient	1,028				
5	Cement	147	1,500	221,000	Ambient					
6	Filled Drums	224	1,680	377,000	Ambient	1,028				
7	Filling Station Vent (d)				Ambient					

a. Fraction of input radioactivity (Table 4.7.33).

b. Characterized in Primary Waste Table 3.3.39.

c. Characterized in Secondary Waste Table 3.52.

d. 20 m³/hr of air.

TABLE 4.7.46. Treated Waste from MOX FFP Cement Immobilization

Waste Type and Surface Dose Rate Class	Volume ^(a) m ³ /yr	Density kg/m ³	Volume Ratio Treated/Untreated	Drums Per Year	Radioactivity Factors ^(b)
Cement Immobilized Wet and Particulate Waste					
<0.2 R/hr (1×10^{-4} R/hr)	123	1,910	1.3	584	²⁴¹ Am = 0.985 Other = 0.318
Cement Immobilized Incinerator Ash and Scrubber Solution					
<0.2 R/hr (0.002 R/hr)	225	1,680	1.7	1,071	²⁴¹ Am = 0.015 Other = 0.682

a. Treated volume based on container volume.

b. Fraction of facility input (Table 4.7.33).

Major Process Equipment. The CIF has the following eight major system components:

- waste feed system
- cement feed system
- filling and mixing station
- capping and decontamination stations
- container transfer cart
- bridge crane
- recovered ammonia storage
- control module.

Waste Feed System. The waste feed system is conceptualized to receive untreated waste, neutralize and evaporate ammonia, if present, and deliver the waste to the drums for immobilization in cement. The specific components of the waste feed system are the 17-m³ (4500 gal) scrap recovery solution receiving and storage tank, the carbon steel 1.4-m³ (50 ft³) lime storage silo and feed system, the scrap recovery solution concentrator, the 8-m³ (2100 gal) miscellaneous waste collection and waste blending tank and associated piping and pumps. All tanks except the lime storage tank are stainless steel. The scrap recovery solution concentrator is a wiped film evaporator. Associated pipes and pumps are sized according to system requirements.

Cement feed system. Dry cement is received and stored in a carbon steel 12-m³ (425 ft³) silo. A vibrating screw feeder sends cement to the drums that already have liquid waste in them.

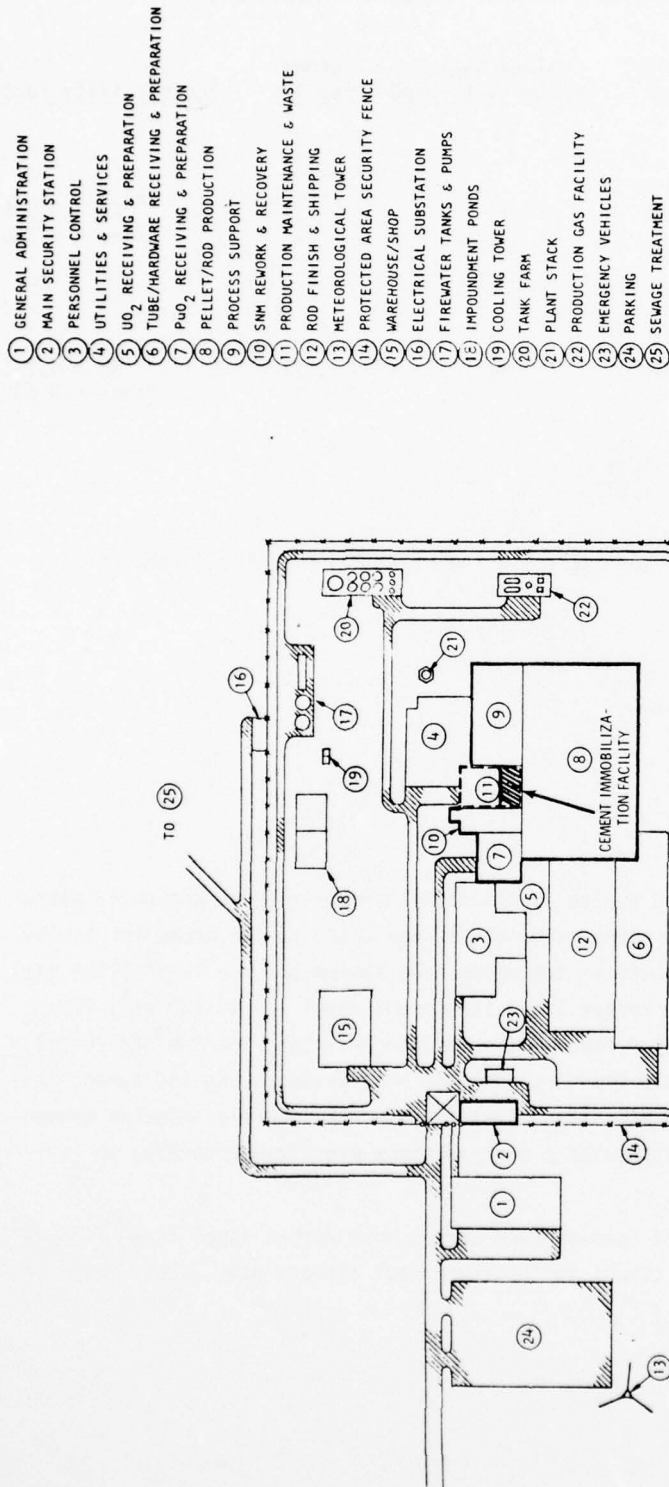


FIGURE 4.7.26. Approximate Location of the Cement Immobilization Facility at the Mixed Oxide Fuel Fabrication Plant

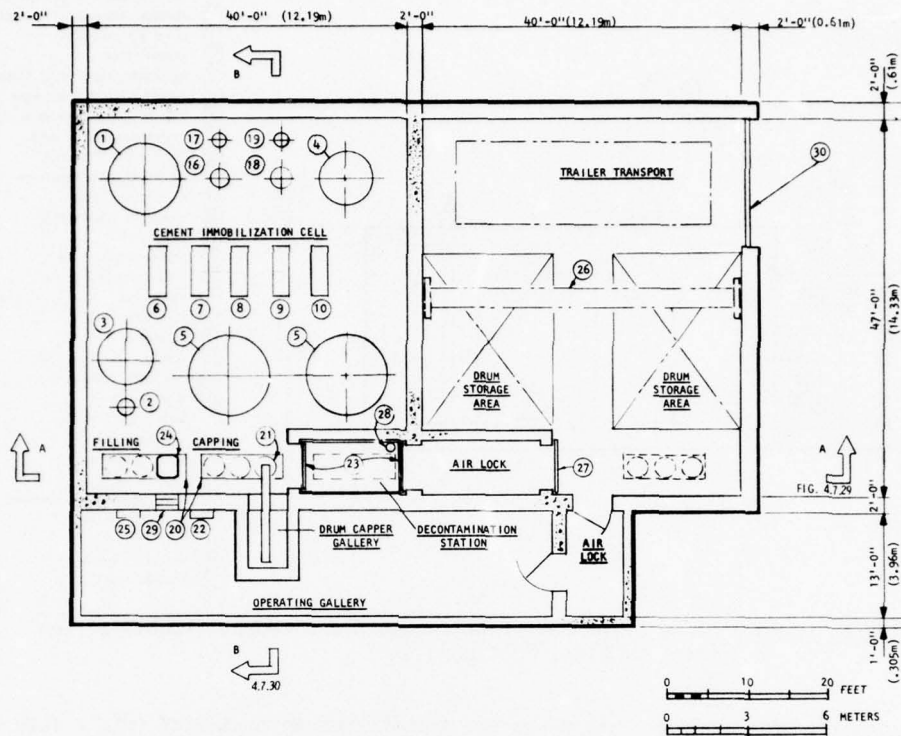


FIGURE 4.7.27. Mixed Oxide Fuel Fabrication Plant Cement Immobilization Facility Plan

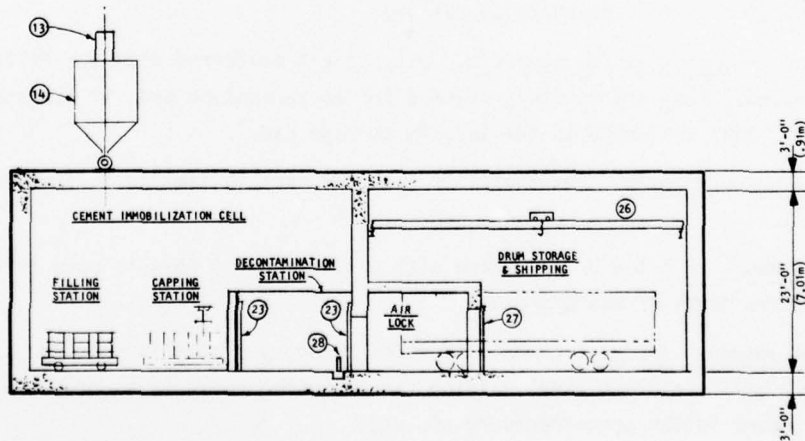


FIGURE 4.7.28. Mixed Oxide Fuel Fabrication Plant Cement Immobilization Facility Plan, Section A-A

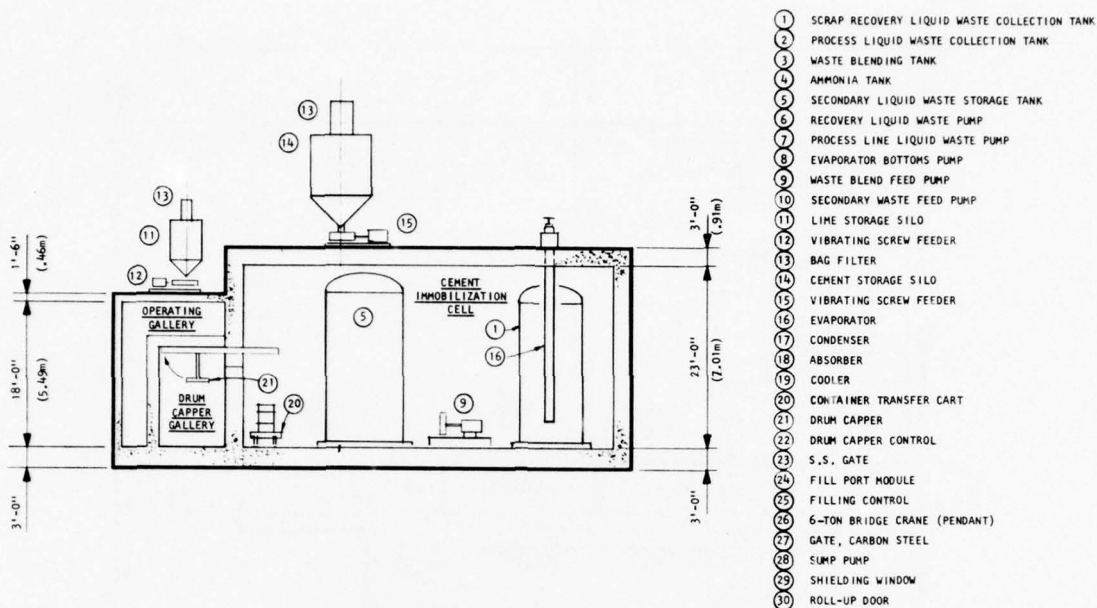


FIGURE 4.7.29. Mixed Oxide Fuel Fabrication Plant Cement Immobilization Facility Plan, Section B-B

Filling and mixing stations. New drums are transferred without lids into a fume hood. Located below a gasketed cover assembly, the drums are raised to the gasket, filled with solution, and then lowered. They are moved to a similar gasketed cover assembly containing an agitator extending below the cover and again raised into the gasket. Cement is metered into the drum with the agitator running. After receiving the specified mixing, the drums are lowered and transferred to subsequent operations.

Capping and decontamination stations. Drums are transferred from the filling station to be remotely capped. They are remotely checked for contamination and, if necessary, decontaminated. Finally, they are moved to the interim storage pad.

Container transfer cart. The container transfer cart is similar to that described in Section 4.7.1.4.

Overhead crane. A 6-ton bridge crane with a 12-m (40 ft) span is used in the storage area to handle the drums of waste product.

Recovered ammonia storage. Ammonia from the recovery system is sent for surge storage to a 10-m³ (2650 gal) stainless steel holding tank. Subsequently it is recycled to the main MOX plant for reuse in the scrap recovery process.

Control module. The control module is similar to that described in Section 4.7.1.4.

Shielding. Minimal radiation shielding is required at the CIF. Calculations have been performed showing that all filled waste drums would have surface dose rates of less than 50 mR/hr. Process equipment provide shielding for unprocessed wastes equal to or greater than the shielding provided for process wastes by the 16-gauge steel drum, thus lessening shielding requirements for the CIF.

4.7.5.5 Operating and Maintenance Requirements for the Cement Immobilization Facility at the Mixed Oxide Fuel Fabrication Plant

The MOX FFP cementation system is highly automated and is operated from a central control panel. The system is operated intermittently on an as-needed basis. Contact maintenance is used on the MOX cement facility. Radiation levels can be reduced by flushing the waste feed system and recycling the flush to the MOX plant radioactive waste system.

Staffing Requirements. Average manpower requirements for the CIF are summarized in Table 4.7.47.

Supplies and Utilities. Based on annual processing times of 285 hr for primary wastes and 540 hr for secondary wastes, the annual utility and supply requirements are summarized in Tables 4.7.48 and 4.7.49.

Hazardous Materials. No unduly hazardous materials are involved in the operation of the CIF.

TABLE 4.7.47. Staffing Requirements for the Mixed Oxide Fuel Fabrication Plant Cement Immobilization Facility

Waste Processed	Manpower Requirements, man-yr/yr		
	Operator	Maintenance	Radiation Monitor
Primary wastes	0.3	0.08	0.05
Incinerator ash	0.02	0.006	0.004
Incinerator blowdown	0.6	0.1	0.08
Miscellaneous secondary solutions	0.008	0.002	0.001
Facility Total	0.9	0.2	0.1

TABLE 4.7.48. Supply Requirements for the Mixed Oxide Fuel Fabrication Plant Cement Immobilization Facility

Waste Processed	Annual Supply Requirements		
	Drums(a)	Cement, kg(b)	Lime, kg(c)
Primary waste	570	1.4×10^5	6.3×10^3
Miscellaneous secondary solution	14	2.8×10^3	0
Incinerator ash	43	5.8×10^3	0
Incinerator blowdown	1028	2.2×10^5	0
Facility total	1654	3.7×10^5	6.3×10^3

a. DOT Specification 17C, 55-gal drums.

b. Portland cement.

c. Ca(OH)_2

TABLE 4.7.49. Utility Requirements for the Mixed Oxide Fuel Fabrication Plant Cement Immobilization Facility

Waste Processed	Annual Utility Requirements			
	Electricity, kWh ^(a)	Air, m ³ (b)	Steam, kg ^(c)	Water Consumed, m ³ (d)
Primary waste	5.4×10^3	1.8×10^4	1.8×10^4	2.1×10^1
Miscellaneous secondary solutions	8.0×10^1	8.0×10^1	0	5.2×10^{-1}
Incinerator ash	3.7×10^2	1.2×10^3	0	1.6
Incinerator blowdown	8.7×10^3	2.9×10^4	0	3.8×10^1
Facility total	1.5×10^4	4.9×10^4	1.8×10^4	6.1×10^1

a. Use rate of 17 kW.

b. 80 to 100 psig, use rate of 55 m³/hr.

c. 120 psig.

d. Use rate of 0.07 m³/hr.

4.7.5.6 Secondary Radioactive Wastes for the Cement Immobilization Facility at the Mixed Oxide Fuel Fabrication Plant

Secondary radioactive wastes generated at the CIF are summarized in Table 4.7.50.

TABLE 4.7.50. Secondary Radioactive Wastes Generated in Cementation of Primary Wastes at the Mixed Oxide Fuel Fabrication Plant

Waste Category	Volume Generated m ³ /yr	Radioactivity Factor(a)
Combustible and compactable waste		
HEPA filters	1.8	10 ⁻⁶
General trash	2.6	10 ⁻⁶
Concentrated liquids, wet wastes, and particulate solids	0.06	10 ⁻³
Solid noncompactable trash and noncombustible waste	0.6	2×10^{-6}

a. Fraction of input activity (Table 4.7.33) in secondary wastes.

4.7.5.7 Emissions From the Cement Immobilization Facility at the Mixed Oxide Fuel Fabrication Plant

No liquid radioactive effluents are released to the environment from the CIF. Vessel and off-gas process vents discharge about 20 m³/hr into the MOX FFP atmospheric protection system (APS). The CIF ventilation system discharges about 11,000 m³/hr into the MOX APS. Airborne radioactive releases from the CIF are the same as for the MOX FFP bitumen immobilization facility, as discussed in Section 4.7.4.7.

An estimate of the integrated release due to minor accidents, Section 4.7.5.9, for this facility is included in Table 4.7.51. It was developed by weighing the minor accident releases by their expected frequencies and summing the quantities for all identified minor accidents. In addition, a contingency was included in the integrated release to account for unidentified minor accidents and to compensate for the uncertainty in expected frequency information. Estimated integrated annual releases due to minor accidents for this technology is shown in Table 4.7.51.

Radioactive releases resulting from operations in the CIF are in the form of particulate aerosols composed of oxides and salts, both soluble and insoluble. Cement dust is also released from the CIF. From primary waste immobilization, 14 kg/yr of cement dust is discharged to the atmosphere. In secondary waste immobilization, 22 kg/yr of cement dust is discharged.

Heat is discharged from the CIF at an estimated rate of 40 kW (1.4×10^5 BTU/hr). Thus from primary waste immobilization, 1.3×10^1 MW-hr/yr (4.5×10^7 BTU/yr) is released. From secondary waste immobilization, 2.0×10^1 MW-hr/yr (6.8×10^7 BTU/yr) is released.

Dominant facility emissions are shown in Table 4.7.51.

TABLE 4.7.51. Emissions from the Mixed Oxide Fuel Fabrication Plant Cement Immobilization Facility

Emissions	Description	Annual Quantity	Radioactivity Release Factor to Atmosphere ^(a)
Gaseous	Process off-gas	Air 1.7×10^4 m ³	A11 1×10^{-17}
	Vaporized excess water	H ₂ O 1.2×10^3 kg	A11 3×10^{-12}
	Minor accident integrated annual release		A11 7×10^{-18}
Cooling tower water	Evaporated (T = 38°C)	5.0×10^4 kg	
	Drift (T = 38°C)	2.4×10^3 kg	
	Blowdown (T = 27°C)	8.6×10^3 kg	
Other	Heat	3.4×10^1 MW-hr (1.1×10^8 BTU)	

a. Fraction of input activity (Table 4.7.33) released to atmosphere. Includes DF from main plant APS where applicable. Released over 35 days/yr.

4.7.5.8 Decommissioning Considerations for the Cement Immobilization Facility at the Mixed Oxide Fuel Fabrication Plant

The CIF is designed to last the anticipated 30-year lifetime of the MOX FFP. The equipment is readily flushable, and it should be possible to decontaminate most of it to 100 mrem/hr for decommissioning.

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4.7.5.9 Postulated Accidents for the Cement Immobilization Facility at the Mixed Oxide Fuel Fabrication Plant

Postulated accidents for the FRP BIF are discussed in Section 4.7.1.9. As in the previous sections, the accidents of the FRP BIF are the umbrella for the MOX FFP CIF. As discussed in Sections 4.7.2.9 and 4.7.4.9, three main differences exist between postulated accidents at the MOX FFP CIF and those discussed in Section 4.7.1.9. First, postulated worst case accidents involve bitumen fires. No equivalent accident is possible at the CIF. Second, only actinides are available for release from the CIF, rather than the activation products, fission products, and actinides of the FRP. Third, the actual quantity of radionuclides available for release at the MOX FFP is less than that for the FRP.

4.7.5.10 Costs for the Cement Immobilization Facility at the Mixed Oxide Fuel Fabrication Plant

Estimates have been made, in mid-1976 dollars, of capital, operating and levelized unit costs. A complete description of the cost estimate bases, assumptions and definitions is given in Section 3.8.

Capital Costs. The capital construction cost estimate for the CIF is summarized in Table 4.7.52.

Operating Costs. Costs of direct labor, materials and utilities are based on the requirements given in Tables 4.7.47, 4.7.48 and 4.7.49. Cost of process materials for cement immobilization at the MOX FFP are a \$0.07 per kg of CaO, \$0.105 per kg of cement, and \$20 each for DOT Specification 17C drums. Maintenance materials costs are estimated at 3% of major equipment. Table 4.7.53 summarizes the operating costs.

TABLE 4.7.52. Capital Cost Estimate for the Mixed Oxide Fuel Fabrication Plant Cement Immobilization Facility

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		10	1,600	100	1,700
Buildings and structures		85	600	1,200	1,800
Bulk materials		65	1,300	800	2,100
Site improvements					
Subtotal of direct site construction costs		160	3,500	2,100	5,600
Indirect site construction costs	40	30	800	1,000	1,800
Total field cost	40	190	4,300	3,100	7,400
Architect-Engineer services					1,500
Subtotal					8,900
Owner's cost					2,600
Total facility cost					11,500
Estimated accuracy range					±25%

TABLE 4.7.53. Operating Cost Estimate for the Mixed Oxide Fuel Fabrication Plant Cement Immobilization Facility

Cost Element	Annual Costs, \$1000s
Direct labor	20
Process materials	60
Utilities	1
Maintenance materials	50
Overhead	50
Miscellaneous	39
Total	220 +50% -25%

Levelized Unit Costs. The levelized unit cost, including levelized capital and operating costs, is shown in Table 4.7.54. The unit cost calculation assumes private ownership of the facilities.

TABLE 4.7.54. Levelized Unit Cost Estimate for the Mixed Oxide Fuel Fabrication Plant Cement Immobilization Facility

Cost Element	Unit Cost, \$/kg HM(a)
Levelized capital charge	7.40
Levelized operating charge	.60
Levelized total unit cost	8.00 ±35%

a. Dollars per kg HM MOX fuel. To convert to \$/kg HM reprocessed, divide by 5.

4.7.5.11 Construction Requirements for the Cement Immobilization Facility at the Mixed Oxide Fuel Fabrication Plant

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating the impact of construction activities.

Project Schedules and Construction Manpower. The schedule for engineering, procurement, and construction of the CIF is an integral factor in the overall schedule for the construction of the MOX FFP. The field labor force estimated for the construction of the CIF is tabulated as follows:

4.7.78

	Man-hours, 1000s
Manual field labor	190
Nonmanual field labor	40
Total field labor	230

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials, and services provided at the site of the MOX FFP; offsite costs are those for all services provided, equipment fabricated and/or assembled, and material purchased elsewhere. The distribution of total costs between these categories is shown below:

	Costs, \$1000s
Onsite	4,000
Offsite	7,500
Total	11,500

Site Requirements. The CIF requires about 520 m^2 (5600 ft^2) within the MOX FFP site.

Water. Water used during the construction period will be approximately $3,000 \text{ m}^3$ ($0.8 \times 10^6 \text{ gal}$).

Construction Materials. Materials committed to facility construction are:

Concrete	1,700 m^3	(2200 yd^3)
Steel	340 MT	(380 tons)
Copper	4.5 MT	(5 tons)
Lumber	100 m^3	(45 MFBM)

Energy. Energy resources used during construction will be:

Propane	26 m^3	(7,000 gal)
Diesel fuel	265 m^3	(70,000 gal)
Gasoline	190 m^3	(50,000 gal)
Electricity		
Peak demand	300 kW	
Total consumption	200,000 kWh	

Transportation Requirements. No separate transportation requirements for the CIF have been identified beyond those for the MOX FFP.

4.7.5.12 Effects of Fuel Cycle Options

The CIF would not be required for the once-through fuel cycle or the uranium-recycle-only fuel cycle. The facility and process described here apply only to the uranium-plutonium recycle fuel cycle.

4.7.6 Other Immobilization Alternatives at a Mixed Oxide Fuel Fabrication Plant

Two types of immobilization alternatives exist for this system--feed stream treatment alternatives and technology alternatives. The various technology alternatives for radioactive

waste immobilization are discussed in detail in Section 4.7.3. Thus, only MOX FFP feed stream alternatives are discussed here.

There is only one feed stream alternative at the MOX FFP for the radioactive waste immobilization facilities. This is the option to not incinerate, thus removing the incinerator ash and scrub solution from the feed stream of the immobilization facility. As discussed in Section 4.7.3, the decision to not incinerate represents a throughput savings for the immobilization facilities, while imposing a substantial increased throughput requirement on trash packaging. These factors, as well as costs, packaged waste integrity, and radiation levels, must be weighted prior to making a decision to incinerate.

The impact of incineration on the throughput at the MOX FFP CIF and BIF is summarized in Table 4.7.55. The potential supplies, utility, and manpower requirements at the CIF and BIF with and without incineration are shown in Table 4.7.56.

TABLE 4.7.55. Summary of Mixed Oxide Fuel Fabrication Plant Incinerator Ash and Blowdown Immobilization Requirements

Feed	Treatment	Volume m ³ /yr	Density kg/m ³	Activity, Ci/yr	Drums/yr
Ash	Untreated	8	240	72,500	--
	Bitumen	3	1,300	72,500	16
	Cement	9	1,640	72,500	43
Scrubber Solution	Untreated ^(a)	127	1,020	100	--
	Bitumen	11	1,300	100	54
	Cement	216	1,800	100	1028

a. Unconcentrated scrub solution.

4.7.7 Physical Protection and Safeguard Requirements for Waste Immobilization Facilities

Wet waste and particulate solid waste immobilization facilities and the materials they produce are not attractive targets for sabotage or theft. The wastes processed in these facilities at both FRP and MOX-FFP contain only a fraction of the plutonium contained in spent fuel, and they have relatively low concentrations of other radioactive nuclides as well. If an adversary succeeded in stealing some of these wastes, he would likely have insufficient resources to isolate enough plutonium to make an explosive device.

Complicating any attempt at theft or sabotage of these wastes is their inaccessibility. Most of the wastes in these facilities are immobilized in cement or bitumen and placed in 55-gal drums, thus making the wastes both inaccessible and difficult to pulverize. Because of this, deliberate dispersal of the contents of a drum by an adversary is unlikely. Furthermore, the wide range of radioactive material concentrations would tend to make the results of either theft or sabotage unpredictable, thus adding to the unattractiveness of these wastes.

TABLE 4.7.56. Effects of Incineration Option on Annual Requirements for Supplies, Utilities, and Manpower at the Mixed Oxide Fuel Fabrication Plant Immobilization Facilities

Feed Option	Supplies and Utilities				Manpower, man-yr		
	Drums,	Binder, (a) kg	Electricity, kWh	Air, m ³	Steam, kg	Water, m ³	Processing Hours
At Bitumen Immobilization Facility							
Ash	16	2.0×10^3	4.7×10^2	3.0×10^1	1.4×10^3	1.1	5
Scrub solution	54	6.6×10^3	1.0×10^5	6.2×10^3	2.9×10^5	3.8×10^2	1030
Total Incineration	70	8.6×10^3	1.0×10^5	6.2×10^3	2.9×10^5	3.8×10^2	1035
Total without Incineration	460	7.7×10^4	1.2×10^5	7.3×10^3	3.4×10^5	4.3×10^2	1200
Total with Incineration	530	8.6×10^4	2.1×10^5	1.4×10^4	6.3×10^5	8.1×10^2	2235
At Cement Immobilization Facility							
Ash	43	5.8×10^3	3.7×10^2	1.2×10^3	0	1.6	22
Scrub solution	108	2.2×10^5	8.7×10^3	2.9×10^4	0	3.8×10^1	514
Total Incineration	1,071	2.2×10^5	9.1×10^3	3.0×10^4	0	4.0×10^1	536
Total without Incineration	584	1.4×10^5	5.5×10^3	5.5×10^3	1.8×10^4	2.2×10^1	292
Total with Incineration	1,654	3.6×10^5	1.5×10^4	3.6×10^4	1.8×10^4	6.2×10^1	828

a. For BIF, binder is bitumen; for CIF, binder is cement.

Immobilization facilities for wet wastes and solids are located within vital areas of an FRP or MOX-FFP. The physical protection normally afforded these areas provides adequate safeguards for these materials.

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4.8 OFF-GAS PARTICLE REMOVAL SYSTEMS

4.8 OFF-GAS PARTICLE REMOVAL SYSTEMS

Off-gas and ventilation air from processes and operations associated with fuel reprocessing, mixed-oxide fuel fabrication and spent fuel storage contain radioactive particles. Principal sources of these particles are:

- condensation processes in which a supersaturated gas condenses on a small nucleus or cluster of molecules
- homogeneous chemical gas reactions that yield solids
- suspension of fine solids from corroding surfaces
- air suspension from bulk powders,⁽¹⁾

These small particles are usually solids but can occur as liquid droplets. Their release to the environment as part of the effluent stream of a fuel cycle facility must be tightly controlled; particle concentration in effluent streams must not exceed limits set by Federal Regulations.⁽²⁾ The goal is to limit releases so that people in the vicinity are exposed to the lowest concentrations reasonably achievable.

Existing technology permits radioactive particle removal systems of almost any design efficiency.⁽¹⁾ These systems can be tailored to have long operating lives, and high capacities, to be resistant to a variety of corrosive gases, and to be relatively insensitive to wide fluctuations in humidity. Available options offer a high degree of resistance to fires, earthquakes, and severe weather stresses such as overpressure during tornadoes. Over 30 years of experience with hundreds of installations have shown particle removal systems to be highly reliable, even when plant upsets and nonstandard conditions have occurred.

Particle removal in nuclear facilities is accomplished almost entirely by dry passive systems of filters. Some facilities may use other kinds of air cleaning methods as well, but virtually all gaseous effluent systems incorporate a passive cleaning element (i.e., a filter) as the final air cleaner before ventilation air is discharged to the atmosphere.

Filter units for dry radioactive particle removal systems often employ replaceable filters; they may, however, be designed and installed as a permanent structure to be used to capacity, then retired. When the efficiency of such a permanent unit becomes substantially impaired, the unit is withdrawn from service, isolated in place, and a similar unit that has been constructed alongside is placed in service.

The following subsections discuss in a general way the kinds of filters used in dry particle removal systems. These filters fall into two basic categories: 1) prefilters and 2) high-efficiency particulate air (HEPA) filters. These two types of filters are used in various combinations to make up filtration (or particle removal) systems suited to the needs of a particular fuel cycle facility. A very specialized and large-scale application of the prefilter/HEPA filter particle removal system is the atmospheric protection system (APS) at a fuel reprocessing plant (FRP). This system, which is the final filtration step for process and ventilation air before its release to FRP stacks, is discussed in a separate section for this report, Section 4.11. Possible alternatives to dry particle removal system are discussed later in this section.

4.8.2

4.8.1 Prefilters

Prefilters are used to remove most airborne particles larger than 10 μm ; they are less efficient for smaller particles. Prefilters are available in various shapes, sizes, filter media and efficiencies. In many applications it is desirable to have modular units that permit assembly of large filter banks by arranging many prefilter units in rows and columns in appropriate rigid supporting structures. Each modular prefilter has its own sealing gasket and can be installed or removed without affecting its neighbor module. A common face dimension for the modular prefilter is 61 x 61 cm (2 x 2 ft), which matches the dimension of a frequently used HEPA filter unit. The depth of the filter will range from as little as 2.5 cm (1 in.) to 61 cm (2 ft).

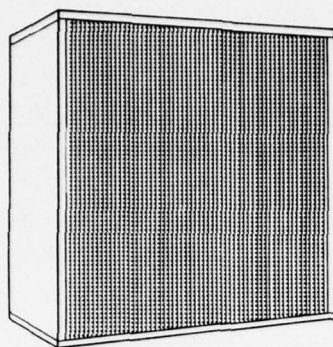
Prefilter construction and media are variable, depending on the performance criteria for the filtering system in which they are used. Prefilters are classified as Group I, II or III, depending on their construction and efficiency. In the simplest, least efficient system, panel filters may be used. These are known as viscous impingement filters because of the low-density filter medium used and the filtering mechanism and are represented most typically by such filters as home furnace filters. The filter medium usually is glass fiber that has a very low density (highly porous packaging). The filters are coated with a sticky resin to assist retention of particles.

The most efficient prefilters (Group III) are more complex in their design. A commonly used configuration is the extended medium type. This type of prefilter consists of a supporting frame into which is sealed the filter medium. The filter medium is a web of glass fibers, or high-porosity paper, folded back and forth over corrugated spacers. This permits a large filter area to be incorporated into a small volume of the filter unit. These units are used until dust loading is sufficient to produce an intolerable pressure drop; the filter unit as a whole is then removed and discarded and a new unit is installed.

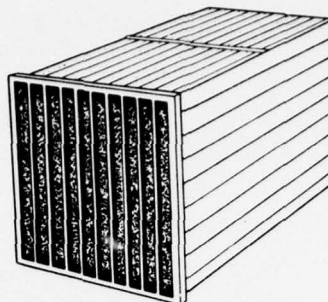
A second typical Group III prefilter is the bag type. This unit consists of a metal frame with modular filter face perpendicular to the airflow, matching HEPA unit dimensions used downstream. The filter mechanism is a fabric, frequently a mat of glass fibers, shaped into bag-like tubes that may or may not be supported by spacer framing. The individual bags, or multiple bags, may be removed when pressure drop becomes too great and then be replaced with new units.

A third common Group III prefilter is made up of V-shaped frames packed with glass fibers. These frames are inserted into a support that makes up a module. Filter frames can be replaced when dust loading is excessive. Figure 4.8.1 illustrates the three types of Group III prefilters described here.

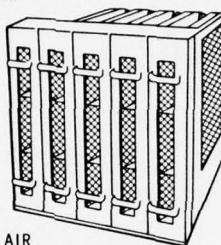
Table 4.8.1 classifies the three groups of prefilters relative to HEPA filter efficiencies, based on the results of atmospheric dust spot tests and arrestance tests. Dust spot test efficiency is measured by comparing the darkness of a filter that has drawn atmospheric air for a given period with the darkness of a like filter paper drawing the same volume of air after the air has passed through the first filter. The arrestance of a prefilter is the fraction of a test dust stopped by the filter. The test dust is carefully sized and dispensed in a standard way.⁽³⁾



A. EXTENDED-MEDIUM, DRY-TYPE, THROWAWAY GROUP III AIR FILTER, WITH GLASS FIBER MEDIUM, SEPARATORS, AND MINERAL-BOARD CASES.



B. BAG-TYPE, REPLACEABLE-MEDIUM GROUP III AIR FILTER. (COURTESY CAMBRIDGE FILTER CORP.)



C. REPLACEABLE-MEDIUM GROUP III AIR FILTER, WITH WIRE MEDIUM SUPPORTS AND INDIVIDUALLY REMOVABLE CORE SEGMENTS. (COURTESY AMERICAN AIR FILTER CO.)

FIGURE 4.8.1. Typical Group III Prefilters

TABLE 4.8.1. Classification of Common Air Filters According to Efficiency⁽⁴⁾

Group	Efficiency	Filter Type	Stain Test Efficiency, %	Arrestance, ^(a) %
I	Low	Viscous impingement, panel type	<20 ^(a)	40-80
II	Moderate	Extended medium, dry type	20-60 ^(a)	80-96
III	High	Extended medium, dry type	60-98 ^(b)	96-99
HEPA	Extreme	Extended medium, dry type	100 ^(c)	100

a. Test using synthetic dust.

b. Test using atmospheric dust.

c. Reference 3.

The decontamination factor (DF) for removal of radioactive particles by a prefilter can vary depending on the quality of the prefilter. Table 4.8.2 compares particle removal for the three groups of prefilters and the HEPA filter. For effluent release calculations, a DF of 10 (90% efficiency) is a reasonable assumption for Group III prefilters.

4.8.4

TABLE 4.8.2. Comparison of Air Filters by Removal Efficiency for Various Particle Sizes⁽⁴⁾

Group	Efficiency	Removal Efficiency by Particle Size, %			
		0.3 μm	1.0 μm	5.0 μm	10.0 μm
I	Low	0-2	10-30	40-70	90-98
II	Moderate	10-40	40-70	85-95	98-99
III	High	45-85	75-99	99-99.9	99.9
HEPA	Extreme	≥ 99.97	99.99	100	100

Prefilters are characterized by a much more open medium than HEPA filters and thus give a much lower pressure drop. Their main purpose in effluent systems is to lengthen the life of the more expensive high efficiency filters. Prefilters are intended to remove the usual ambient dust entering a facility in the ventilation air. Lint, rust particles, concrete dust, and dust from chemical makeup areas are principal sources. Service life of a HEPA filter will generally be increased by two to three times when the filter is used in combination with the appropriate prefilter. However, it is not always cost effective to install prefilters. If the air to be filtered is "clean," less than ~ 2 mg of dust per m^3 (~ 1 grain per 1000 ft^3), prefilters should not be considered except to reduce the accumulation of dust in ducts or to provide some measure of protection from fires or overpressure surges.

A clean prefilter will show a pressure drop on installation of about 0.8 cm H_2O , and will be replaced when pressure rises to about 3.8 cm H_2O . The lifetime of these filters will be determined by the dust loading in the ventilation air (which is rough-filtered at the supply fans), and the dust, lint, and other sources within the plant. Prefilters will be replaced once a year or less often.

4.8.2 HEPA Filters

High-efficiency particulate air filters are used almost universally in nuclear installations.^(5,6) These filters and the technology for their use have been developed over many years in the nuclear energy industry.^(7,8)

HEPA filters are encased in wood or metal. They are usually of a specially-formulated glass fiber mat with a small amount of binder. When resistance to hydrofluoric acid is essential, asbestos fibers are combined with cellulose fibers to make a resistant web. HEPA filters are available in several modular sizes. The most common module for large installations has a cross section area of 3721 cm^2 (576 in.^2) and is 29 cm (11.5 in.) deep. This module will filter $0.47 \text{ m}^3/\text{sec}$ (1000 cfm). It weighs 16 to 20 kg (35 to 45 lb) and has a volume of about 0.1 m^3 (4 ft^3). Approximately 18.4 m^2 (200 ft^2) of the medium is used in each module; thus, the nominal medium face velocity is 0.025 m/sec (5 fpm).

Strict quality assurance at the manufacturing stage and subsequent manufacturer and independent test station efficiency measurements ensure that every filter will be at least 99.97% efficient for removing particles of $0.3\text{-}\mu\text{m}$ nominal diameter. Larger or smaller particles

are retained more efficiently. Recent experience has shown that many filters will be greater than 99.99% efficient at the time of installation.⁽⁹⁾ Detailed instructions, including installation and testing directions, are available to designers of systems using HEPA filters.⁽⁴⁾ Essential to HEPA filtration systems is the capability for in-place testing with a test aerosol. Other features of the filter specification establish the fire resistance, moisture resistance, dimensional tolerances, and the gasket quality.

Although fiber modules must show efficiencies of 99.97% or greater prior to installation, a more conservative efficiency is recommended for calculating the anticipated in-service efficiency. Potential deterioration with service or minor leaks developing because of imperfect sealing will decrease efficiency. Two or more filters are frequently used in series, and the first filter may exhibit a higher efficiency than the subsequent filters. The fractional penetration exhibited by multiple filters for plutonium oxide aerosols of 0.22 to 1.6 μm aerodynamic median activity diameter (AMAD) was recently reported, as Table 4.8.3 shows.⁽¹⁰⁾

TABLE 4.8.3. Penetration of HEPA Filters Operating at Full Flow by $^{238}\text{PuO}_2$ Aerosol with 0.22 to 1.6 μm AMAD

HEPA No.	Penetration Rating	Maximum Penetration, $\times 10^6$	Mean Penetration, $\times 10^6$	Standard Deviation, $\times 10^6$	N(a)
1	Low ^(b)	21	8.3	7.1	20/20
1	High ^(c)	108	32	33	23/24
2	Low ^(c)	31	17	7.2	22/23
2	High ^(c)	159	106	38	15/15
3	Low ^(b)	78	71	10	6/8

a. Number of data points passing "outliers" test versus data points available.

b. 20 to 150 $\times 10^{-6}$ by 0.3 μm dioctylphthalate (DOP) quality assurance test.

c. 151 to 300 $\times 10^{-6}$ by 0.3 μm DOP quality assurance test.

For comparison these penetrations are grouped and converted to efficiency in Table 4.8.4. These results show that the second and third filters in series are marginally less efficient in filtering the aerosol than the first filter. A three-stage HEPA filter bank based on these data should exhibit a decontamination factor of 10^{12} if the lesser test of efficiency filters are used as representative.

The efficiencies shown in Table 4.8.5, though conservative, are recommended for estimating anticipated releases. These conservative DFs allow a margin of safety for accidental situations where some deterioration from aging is accounted for or for situations where the aerosol reaching the filters may be many times greater than that nominally assumed for the steady state.

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TABLE 4.8.4. Efficiencies of HEPA Filters Operating at Full Flow for Removing Particles of $^{238}\text{PuO}_2$ Aerosol with 0.22 to 1.6 μm AMAD⁽¹⁰⁾

Filter Category	Efficiency, %	
	Minimum	Mean
Group A ^(a)		
First filter	99.9979	99.9992
Second filter	99.9969	99.9983
Third filter	99.9922	99.9929
Group B ^(b)		
First filter	99.9892	99.9968
Second filter	99.9841	99.9894
Third filter	---	---

- a. Filters shown to range in efficiency from 99.998 to 99.985% in DOP quality assurance test.
 b. Filters shown to range in efficiency from 99.998 to 99.970% in DOP quality assurance test.

TABLE 4.8.5. HEPA Filter Efficiencies Recommended for Design Calculations

Number of Filters	DF	Efficiency, %	Cumulative DF
1	1.0×10^3	99.9	1.0×10^3
2	1.0×10^3	99.9	1.0×10^6
3	1.0×10^3	99.9	1.0×10^9
4	1.0×10^3	99.9	1.0×10^{12}

The efficiencies of all individual units prior to installation are measured using a test aerosol 0.3 μm in diameter. The 0.3- μm size was chosen because it represents the most difficult particle size to remove given the design face velocity of the filter medium. Radioactive aerosols arising from light water reactor fuel cycle operations may be larger or smaller than this most difficult size to filter. Efficiency of removal could be as high as 100% for larger particles and could approach 100% for the extremely small particles that have high diffusion coefficients.

Modular design permits HEPA filters to be replaced when pressure drop becomes excessive and prevents adequate flow. A new HEPA filter will show a pressure drop of about 2.5 cm (1 in.) at rated flow. The filter unit will be replaced when pressure drop reaches about 10 cm (4 in.) H_2O . The working life of a HEPA filter will vary widely depending on the particle loading in the air sampled and on the size of the particles. As stated earlier, prefilters will increase the life

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of the more expensive HEPA filters. An unprotected HEPA filter will typically require changing in three years.⁽¹¹⁾ A second-stage HEPA filter, or one protected with a 90% dust stain efficiency, may not need replacing for five years or more, depending upon the circumstances. Filter modules removed from service are disposed of as solid radioactive waste.

4.8.3 Alternative Particle Removal Systems

Other types of particle removal systems are used in industrial air cleaning applications but have not found extensive application in nuclear facilities. The following systems are representative.

4.8.3.1 Electrostatic Precipitators

Electrostatic precipitators remove particles by first imparting a unipolar charge to the particles, passing the particles through a high voltage field. The collectors are high voltage electrode wires centered between plates. Although widely used in industry for reducing emissions, these precipitators have features that make their use in nuclear fuel cycle plants unattractive. Under close control an electrostatic precipitator can be 99% efficient. Efficiency will drop to zero during a power failure or other electrical equipment malfunction. Another drawback is the potential for deposited particles to slough off the collector plates and be reentrained in the gas stream. For these reasons, electrostatic precipitators are not used in nuclear facilities.

4.8.3.2 Bag Filters

Fabric filters in the form of long vertical sleeves are used in industries where an airborne effluent is to be recovered. Efficiencies of greater than 99% are achieved. This type of filter could be applied as a prefilter; efficiencies would generally not be adequate as a final filter. Bag filters, however, would require greater space and are more expensive to maintain than the prefilters commonly used in nuclear facilities.

4.8.3.3 Wet Collectors

A variety of wet scrubber systems are used for removing particles and gases from effluent streams. Most applications do not insure the removal of submicron-sized particles, although venturi scrubbers and other scrubbers that impart great energy to the fluid can provide 99% removal. A principal disadvantage of wet scrubbers when applied to radioactive particle removal is the creation of a liquid waste stream. Thus, the scrubber fluid would have to be converted to a form suitable for disposal. Efficiency is dependent on maintaining control of scrubber flow; this control requirement introduces possible variable efficiency, which cannot be tolerated in radioactive particle removal systems. Although wet scrubbers have been used for relatively low-volume, radioactive-particulate-laden streams, they are more commonly used in nuclear facilities for removing soluble volatile components in the off-gas, such as nitrogen oxides. In these applications, a particulate DF is usually realized but is always backed up with HEPA filters or prefilter/HEPA filter combinations.

4.8.4 Physical Protection and Safeguards Requirements for Off-Gas Particle Removal Systems

Filters for particle removal at fuel reprocessing plants (FRPs) are neither attractive nor accessible targets for theft. The process and ventilation filters at an FRP contain essentially only long-lived fission products and the structures in which the filters are housed as well as the health and safety risks (the dose rates exceed 10 R/hr) to anyone handling the filters, make them difficult to remove. Filters on glove boxes where PuO_2 is processed in a FRP and in a MOX FFP are potential targets for theft because they accumulate PuO_2 . Therefore, even the area where spent filters are stored would be safeguarded as a material access area (see 10 CFR 73).

Sabotage of process off-gas filters by use of explosives or projectiles could result in release of radioactive particulate material to the environment. However, at least two stages of filtration normally protect the environment and simultaneous sabotage of both is very improbable. In addition, the off-gas filtration subsystems of a plant would be moderately inaccessible. Even if some filter banks were made inoperable, plant design would allow for bypassing and repairing them without affecting the integrity of the plant's filtration system. The consequences of some of the accidents discussed in 4.1.2.9 give an indication of the consequences that might result from disruption of a portion of the process off-gas filtration system.

The Off-Gas Particle Removal Systems in both an FRP and a MOX FFP would be safeguarded under the physical protection systems of these facilities. In addition, the first stage of filtration would be in or adjacent to the operating areas and would also be protected under the safeguards provided to a vital area.

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4.9 FUEL REPROCESSING PLANT DISSOLVER OFF-GAS TREATMENT

4.9 FRP DISSOLVER OFF-GAS TREATMENT

A major source of radioactive gaseous waste from a fuel reprocessing plant (FRP) is the off-gas produced during dissolution of the spent nuclear fuel. The dissolvers operate under highly acidic conditions, and essentially all of the iodine-129, carbon-14, and krypton-85 in the spent fuel are volatilized into the dissolver off-gas (DOG). Part of the tritium inventory is volatilized as water vapor, and a small fraction of the semivolatile fission products, such as ruthenium-106, is transported by entrainment or as gaseous species. The major constituent of the dissolver off-gas is air, which is used as an agitation medium to stir the dissolver contents.

4.9.1 Dissolver Off-gas Iodine Recovery

Release of radioactive iodine to the atmosphere represents a biological risk since iodine tends to be taken up in the food chain and to concentrate in the human thyroid. To reduce this risk during early production of defense plutonium in the United States, radioactive iodine (mostly ^{131}I) from dissolver off-gas was removed by using silver nitrate-coated ceramic saddles (90-95% efficient) and later by caustic scrubbing. In reprocessing power reactor fuels, the short-lived iodine-131 (8 day half-life) can be controlled simply by delaying reprocessing until this nuclide has decayed to an insignificant concentration. Thus, researchers are concerned presently with removing the long-lived iodine-129 (1.6×10^7 yr half-life).

4.9.1.1 Process Alternatives for Dissolver Off-gas Iodine Recovery

Iodine recovery can be accomplished by aqueous scrubbing processes or by solid adsorbent processes. Caustic scrubbing technology has been applied in numerous fuel reprocessing systems and is considered fully developed.⁽¹⁾ However, caustic scrubbing has a low (50-90%) iodine-removal efficiency and therefore has limited applicability for iodine removal in the commercial fuel reprocessing industry.

Mercuric nitrate-nitric acid scrubbing has been developed⁽¹⁾ and is described in the flowsheet⁽²⁾ for the Barnwell Nuclear Fuel Plant Separations Facility developed by Allied General Nuclear Services (AGNS). The system is reported to be effective (99% recovery) in removing elemental iodine from off-gas streams but ineffective for organic species because of very slow reaction kinetics for organic iodides. Using this system, the reference FRP would generate approximately 40 m^3 of 0.4 molar mercuric nitrate solution per year. Laboratory-scale development has been conducted to concentrate this waste; AGNS suggests that it can be absorbed on clay and packaged in fuel residue containers.

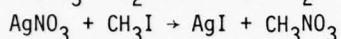
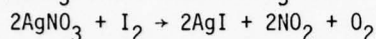
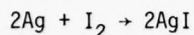
In the Iodox scrubbing process,⁽¹⁾ iodine is removed from the off-gas stream by scrubbing with 20 to 22 molar nitric acid. Although scrubbing column technology has been demonstrated at Oak Ridge National Laboratory (ORNL),⁽³⁾ long-term system capacity and corrosion effects on applicable construction materials need to be determined.

The selected reference process is the most efficient iodine removal technique known. Solid adsorbent materials impregnated with silver or silver nitrate are effective for removal of iodine and its compounds from process off-gas streams.^(4,5) Silver-loaded adsorbents achieve

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a relatively high adsorption efficiency because of the great affinity of volatilized iodine for silver ions. The process is costly but produces compact solid iodine waste that can be easily packaged for disposal.

Candidate sorbent matrix base materials include zeolites and several types of silicates. The chemical reactions postulated for silver-nitrate-impregnated substrates are:



Testing of both commercially-available sorbents and laboratory-prepared sorbents is in progress at both government and industry laboratories to fully assess and optimize process-scale applications. Preliminary results indicate that other metal-loaded adsorbents (cadmium, copper, sodium, lead, zinc) do not have sufficient iodine loading capacity for bulk iodine removal.⁽⁵⁾

Of the various silver-loaded adsorbents tested to date, the highest loading of iodine per gram of silver had been obtained with silver-nitrate-impregnated amorphous silicic acid. Fractional penetration of the CH_3I and elemental iodine through a silver-treated bed is a function of many variables.^(6,7) However, experiments⁽⁴⁾ have indicated that up to 98% of the silver is available for reaction. Consequently, this material was chosen for use in the reference system for iodine recovery. An iodine loading based on 80% of the silver reacting (0.94 gram of iodine per gram of silver) was conservatively assumed for design purposes.

High concentrations of oxides of nitrogen (NO_x) and water vapor in an air stream can also reduce the efficiency and capacity of silver-treated materials. However, the effect does not appear to be significant at NO_x concentrations below 10 vol% and a dew point of below 75°C.^(4,6)

4.9.1.2 Design Basis for the Dissolver Off-gas Iodine Recovery System

The following assumptions were made in the design of the reference facility:

- The entire DOG treatment system operates 300 days a year and treats off-gas from the 2000-MTHM/yr reference FRP for recovery of iodine using silver zeolite beds.
- The FRP fuel shear off-gas is combined with the DOG.
- The design volumetric flow is approximately $2.8 \text{ m}^3/\text{min}$ ($100 \text{ ft}^3/\text{min}$).
- The iodine recovery system is incorporated as an integral part of the FRP.
- The iodine recovery system retrieves both ruthenium and iodine prior to release of the DOG to the atmospheric protection system (APS).
- The system is designed to achieve a decontamination factor (DF) of 10^5 for particulate ruthenium and other particles, 10^4 for volatile ruthenium, and 10^3 for iodine.

4.9.1.3 Dissolver Off-gas Iodine Recovery Process

For gas cleanup prior to iodine removal, the dissolver off-gas is routed through: 1) an aqueous scrubber deentrainer for NO_x and particle removal, 2) a ruthenium adsorber and 3) a high-efficiency particulate air (HEPA) filter for particle removal. The off-gas then passes

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through the iodine adsorbers for recovery of volatile iodine, and is either discharged to the APS or becomes the feed stream for the additional recovery of carbon (Section 4.9.2), or krypton (Section 4.9.3), or carbon and krypton (Section 4.9.4).

Table 4.9.1 shows the reference dissolver off-gas composition. A schematic flowsheet for the iodine recovery system is shown in Figure 4.9.1. The material balance is given in Table 4.9.2. Table 4.9.3 characterizes the solid waste resulting from the iodine recovery system. The liquid stream from the scrubber deentrainer is routed to the FRP concentrator system for processing.

The material balance calculations are based on sparging the dissolver with $2.8 \text{ m}^3/\text{min}$ ($100 \text{ ft}^3/\text{min}$) of dry air for agitation. Iodine and bromine are assumed to be completely volatilized in the DOG. Approximately 0.01% of the ruthenium inventory is assumed to be carried in the DOG by volatilization.⁽⁸⁾ An equal fraction (0.01%) of the ruthenium present in the dissolver is entrained in the off-gas particles.

TABLE 4.9.1. Fuel Reprocessing Plant Dissolver Off-gas^(a,b)

Component	Annual Quantity, kg	Radioactivity, Ci/yr	
		Fission Products	
H ₂ O	1.8×10^5	³ H	4.2×10^4
Air	1.6×10^6	¹²⁹ I	6.9×10^1
NO _x	5.1×10^5	⁸⁵ Kr	1.68×10^7
C ^(c)	100	⁹⁰ Sr + ⁹⁰ Y	2.4×10^1
Kr	650	⁹⁵ Zr + ⁹⁵ Nb	2.2
I	470	¹⁰⁶ Ru + ¹⁰⁶ Rh	1.5×10^5
Ru	0.81	¹³⁴ Cs + ¹³⁷ Cs + ^{137m} Ba	6.0×10^1
Br	27	¹⁴⁴ Ce + ¹⁴⁴ Pr	9.6×10^1
		ALL OTHER	2.0×10^1
		TOTAL	1.7×10^7
		Actinides	
		²³⁹ Pu	7.2×10^{-2}
		²⁴¹ Pu	3.5×10^1
		Other Pu	1.2
		²⁴² Cm + ²⁴⁴ Cm	3.4
		ALL OTHER	1.8×10^{-1}
		TOTAL	4.0×10^1
		Activation Products	
		¹⁴ C	1.12×10^3

a. Based on waste characterization Table 3.3.27, assuming uranium and plutonium recycle. 2000 MTHM/yr reprocessed 1.5 years out of reactor.

b. Volume = $1.2 \times 10^6 \text{ m}^3/\text{yr}$.

c. CO₂ in process air is not included.

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Deentrainment. Two mist eliminators, or deentrainers, protect the iodine adsorbers and the HEPA filters by removing entrained dissolver solution from the off-gas. A coarse, mesh pad in the top of the absorber column (first deentrainer) removes approximately 99% of the entrainment. Following this coarse pad, a fine-pad deentrainer removes approximately 99.8% of the droplets larger than $3\ \mu\text{m}$ (primarily to protect the HEPA filter). Decontamination factors for iodine, volatile ruthenium, tritium and particles in the scrubber deentrainer are estimated to be 1, 5, 10 and 100, respectively. In actual plant experience, iodine may be partially removed in the scrubber deentrainer. The resulting scrub stream is sent to the low level concentrator (Figure 3.2.10). The contained iodine then distributes between the VOG stream, the high level liquid waste stream and the recovered HNO_3 and water streams. By suitable treatment of these streams, the release of iodine to the atmosphere by this route is also maintained below 10^{-3} of the input value.

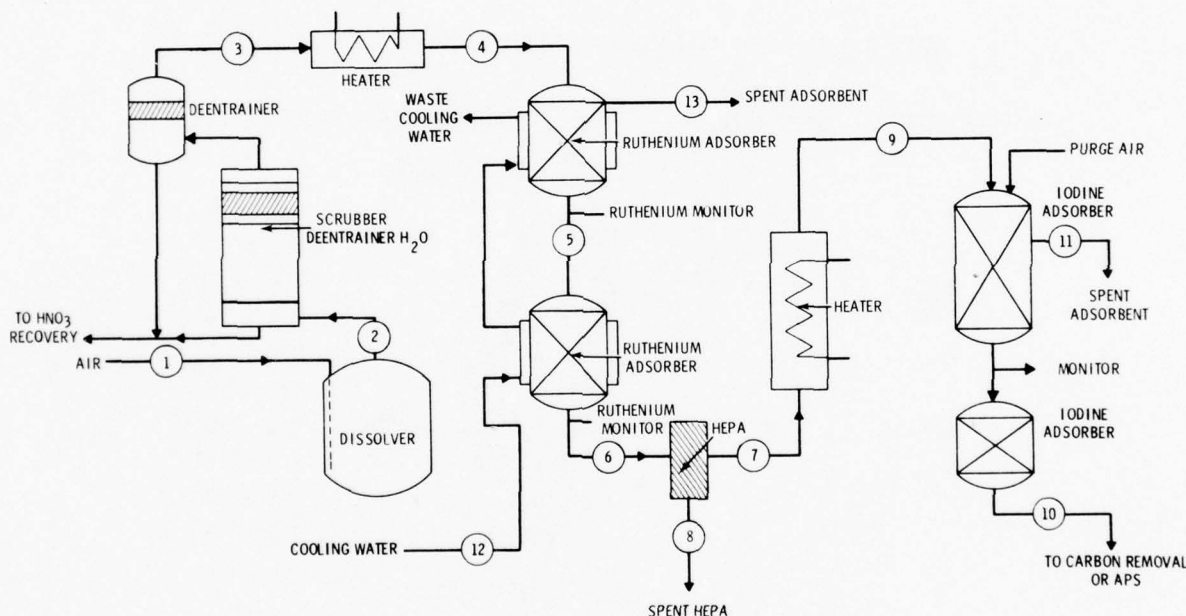


FIGURE 4.9.1. Process Flowsheet for the Iodine Recovery System
(Circled numbers refer to stream numbers in Table 4.9.2)

NO_x Removal. The first deentrainer also includes an aqueous scrubber, or absorber, to remove nitrogen oxides. The scrubber deentrainer reduces the NO_x from the dissolver to less than 2 vol%. Water vapor is reduced to less than 3 vol%, and the absorbed NO_x from the absorber is recycled to the acid recovery system.

The following reactions are involved in the nitrogen oxide absorption process:

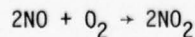
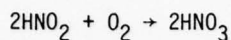
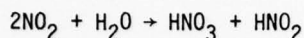
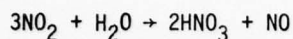


TABLE 4.9.2. Dissolver Off-gas Iodine Recovery Material Balance

Stream Number	Pressure, atm	Temperature, ture, °C	Total Flow, m ³ /hr	Total Flow, kg/hr	Flow by Components, kg/hr										Solid Waste, m ³ /yr	Cooling Water, m ³ /hr		
					N ₂	O ₂	Ar	CO ₂	H ₂ O	H	NO _x	H ₂ O	Br	Kr			Xe	Ru
1	--	35	170 (STD)	219.8	166	50.8	2.79	0.11	--	Trace	--	Trace	--	--	6.6 x 10 ⁻⁴	8.1 x 10 ⁻⁵	--	--
2	1.1	90	222	232.9	166	50.8	2.79	0.16	2.5 x 10 ¹	--	7.12 x 10 ¹	Trace	6.5 x 10 ⁻²	3.8 x 10 ⁻³	0.090	1.30	1.12 x 10 ⁻⁴	6.94 x 10 ⁻⁷
3	1.1	35	184	232.9	166	50.8	2.79	0.16	4.3	--	7.35	Trace	6.5 x 10 ⁻²	3.8 x 10 ⁻³	0.090	1.30	6.2 x 10 ⁻⁶	1.2 x 10 ⁻⁷
4	1.1	45	190	232.9	166	50.8	2.79	0.16	4.3	--	7.35	Trace	6.5 x 10 ⁻²	3.3 x 10 ⁻³	0.090	1.30	6.2 x 10 ⁻⁶	1.2 x 10 ⁻⁷
5	--	45	--	232.9	166	50.8	2.79	0.16	4.3	--	7.35	Trace	6.5 x 10 ⁻²	3.8 x 10 ⁻³	0.090	1.30	5.7 x 10 ⁻⁷	1.2 x 10 ⁻⁷
6	1.0	45	209	232.9	166	50.8	2.79	0.16	4.3	--	7.35	Trace	6.5 x 10 ⁻²	3.8 x 10 ⁻³	0.090	1.30	5.7 x 10 ⁻⁷	1.2 x 10 ⁻⁷
7	1.0	45	209	232.9	166	50.8	2.79	0.16	4.3	--	7.35	Trace	6.5 x 10 ⁻²	3.8 x 10 ⁻³	0.090	1.30	5.7 x 10 ⁻⁷	1.2 x 10 ⁻⁷
8	--	--	--	--	--	--	--	--	--	--	--	Trace	6.5 x 10 ⁻²	3.8 x 10 ⁻³	0.090	1.30	6.2 x 10 ⁻⁹	1.2 x 10 ⁻⁷
9	1.0	150	277	232.9	166	50.8	2.79	0.16	4.3	--	7.35	Trace	6.5 x 10 ⁻²	3.8 x 10 ⁻³	0.090	1.30	6.2 x 10 ⁻⁹	1.2 x 10 ⁻⁷
10	0.76	150	364	232.9	166	50.8	2.79	0.16	4.3	--	7.35	Trace	6.5 x 10 ⁻²	3.8 x 10 ⁻³	0.090	1.30	6.2 x 10 ⁻⁹	1.2 x 10 ⁻⁷
11	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
12	--	45	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	6.6
13(a)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	2.3
14(b)	--	--	3.4	4.4	3.3	1.0	0.057	2.2 x 10 ⁻³	--	--	--	--	--	--	--	--	--	2.5

a. Spent ruthenium adsorbent solid waste volume on 5 year changeout (m³/5 yr).

b. Air purge for 8 hours, prior to adsorbent cartridge removal. This flow is not included in downstream tabulations.



The first reaction is rate-controlling and increases with the partial pressure of the reactants and with decreasing temperature.^(9,10,11) The concentration of NO_x cannot, practicably, be driven below about 1000 ppm in an air stream by absorption in water.

TABLE 4.9.3. Description of Packaged Waste from Iodine Recovery System

Surface Dose Rate	Volume, m ³ /yr	Density, kg/m ³	Containers/yr, 55-Gal Drums	Fraction of Input Activity ^(a)	
				¹²⁹ I	¹⁰⁶ Ru + Rh
<0.2 R/hr (~0.03 mR/hr)	7.6	7 x 10 ²	36	1.0	
>10 R/hr (~250 R/hr)	0.5	7 x 10 ²	2.4		0.05

a. Fraction of input activity from Table 4.9.1.

Ruthenium Recovery. In the next step, silica gel beds are used to remove the ruthenium. Since ruthenium is one of the major contributors to total dissolver off-gas activity, removal at this early stage reduces overall activity throughout the rest of the process. Based on recent experiments in a silica gel bed, a DF of 1000 is achievable for volatile ruthenium.⁽⁸⁾ The back-up ruthenium adsorber is intended to handle unexpected bursts of ruthenium from the dissolver in case of process upset. Two adsorbers in series should yield a combined DF considerably higher than 1000. The adsorbers are operated until ruthenium is detected at the exit or until the beds plug. The gas stream is then diverted to a parallel adsorber and back-up bed. Although one adsorber has a loading capacity sufficient for the lifetime of the plant, the longevity of the adsorber under operating conditions has not been established. It is conservatively assumed that bed change will be required at 5-year intervals.

Following ruthenium recovery, a HEPA filter reduces particulate loading of the gas. No DF is obtained for volatile ruthenium at this filter. The gas is then clean enough for the iodine adsorption bed. An electric heater preheats the gas to 150°C prior to its entering the adsorption bed where the iodine is removed.

Total ruthenium-rhodium activity removed during the off-gas cleanup procedure prior to iodine removal is as follows:

- 4.8×10^2 Ci/day for the scrubber deentrainer
- 2.5×10^1 Ci/day for the ruthenium adsorber
- 2.5 Ci/day for the HEPA filters.

These figures assume: 1) 0.01% volatility and 0.01% entrainment of the ruthenium from the dissolver, 2) a yearly ¹⁰⁶Ru-Rh dissolver off-gas inventory of 1.5×10^5 Ci/yr, 3) the decontamination factors mentioned above, and 4) ¹⁰³Ru-Rh has decayed to a negligible status (0.03 Ci/yr).

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Iodine Recovery. Based on experimental work, an iodine DF of 1000 has been assumed.⁽⁴⁾ Two silver zeolite iodine adsorbers are placed in series, a primary and a back-up. The primary bed is a large bed designed to adsorb all off-gas iodine during a 25-day period of operation. An iodine monitor is located in the gas stream between the primary and back-up adsorption beds. The smaller back-up bed ensures that no iodine losses occur when the iodine monitor indicates breakthrough of the primary bed. When breakthrough occurs, the gas stream is switched to a parallel iodine adsorbent bed held in reserve. As with the ruthenium adsorber, no credit is taken for any iodine removal in the back-up bed, although in practice another DF of up to 1000 might be obtained.

Testing of the silver-zeolite by both industry and government laboratories is currently in progress to determine optimum design parameters. The principal process design features of the iodine adsorbent train can be summarized as follows:

- The bromine-81 would be adsorbed along with the iodine, which would give an equivalent iodine inventory of ~500 kg/yr.
- The silver-zeolite contains 12 wt% silver and has a dry density of 0.68 g/cm³.
- At breakthrough (measured between the fourth cartridge and the back-up bed), at least 80% of the silver in the first three silver-zeolite cartridges is reacted, producing an average loading of 0.078 g I/cm³.
- At each change, only cartridges one through three are discarded; the tail-off and back-up cartridges are then moved to front positions.
- Breakthrough occurs after about 25 days of operation.
- About 36 cartridges of silver-zeolite are used per year.
- Dual adsorber trains are used to permit continuous iodine removal while one or the other is being recharged. The dual system also provides 25 days of reserve capacity for repairs should the operating adsorber malfunction.
- The volumetric flow rate to the iodine adsorbent vessel inlet, given an operating temperature of 150°C, is 4.6 m³/min (163 ft³/min).
- The inlet pressure is 1 atmosphere (14.7 psi); the pressure drop across the total train (principal plus back-up) is approximately 0.24 atm (3.5 psi). The bed is designed for a superficial flow velocity of about 15 m/min (50 ft/min).
- Because of high gaseous activity from krypton-85, the beds must be purged with dry air before discharge to flush out krypton-85 held up in the interstitial void spaces in the adsorbent bed. An 8-hour purge of 3 to 4 m³/hr is assumed.

4.9.1.4 Facility Description for the Dissolver Off-gas Iodine Recovery System

The dissolver off-gas iodine recovery system is designed to be incorporated as an integral part of the reference fuel reprocessing plant (see Section 3.2). The DOG treatment facilities share FRP services, utilities, laboratories, health physics support, operating personnel change areas, maintenance areas, warehousing, shops and offices. The off-gas treatment system is capable of handling the total DOG stream from the reference FRP. The approximate location

4.9.8

If the facilities for iodine recovery is shown on the plot plan of the FRP in Figure 4.9.2. A plan and cross-sectional view of the iodine recovery system are shown in Figures 4.9.3 and 4.9.4. All process equipment is enclosed within Category I cells and galleries, which are constructed of reinforced concrete. Cells are provided with floor pans, sumps and protective coatings to facilitate decontamination and to cope with possible spills. The facilities shown are enclosed within the outer walls of the Category I FRP structure.

Major pieces of equipment within the cell are described below, including the absorber deentrainer, heaters, ruthenium adsorber, HEPA filters, and the iodine adsorber cartridge.

Absorber Deentrainer. The top of the absorber is equipped with a 15-cm diameter deentrainer, which gives a face velocity of 200 m/min in a wire mesh pad (austenitic stainless steel). This results in approximately a 99% entrainment removal efficiency. A normal pressure drop (ΔP) of 5 cm H_2O is estimated for the absorber deentrainer. When the ΔP indicates plugging, the deentrainer is washed, using a wash solution flow of 0.6 ℓ /min.

Deentrainer. The second deentrainer, contained in its own vessel, gives 99.8% removal efficiency for droplet sizes up to 3 μm . A design face velocity of 75 m/min is achieved using a 25-cm diameter vessel. The mesh pad is located 75 cm from the bottom of the 100-cm high vessel. Figure 4.9.5 shows the recommended dimensions of the vessel, which is made of austenitic stainless steel because of the acidic conditions. The nominal deentrainer ΔP is 3 cm H_2O . A spray directed on the bottom of the mesh pad periodically washes this equipment.

HEPA Preheater. The HEPA preheater is an electric heater (1.0 kW) requiring 640 W of power during normal operation. This heater, made of austenitic stainless steel because of possible traces of nitric acid mist, raises the gas temperature by 10°C.

Ruthenium Adsorbers. The ruthenium adsorbers (primary and back-up) are silica gel adsorption beds designed for a face velocity of 7.2 m/min. Each bed is 75 cm in diameter and is 1.7 m in length. Two beds, made of austenitic stainless steel, are installed in series between a ruthenium monitor. The monitor is set to alarm when breakthrough occurs and ruthenium penetrates the bed. At that time, gas flows are diverted to a parallel adsorber train. Based on the ruthenium flows described on Table 4.9.2, each bed would be adequate for over 70 years of plant operation. However, since these silica gel beds are the first processing steps downstream from the adsorber-deentrainers, particle removal mechanisms and adsorption of other species may also take place. The bed life has been estimated to be about 5 years. Bed change is accomplished remotely by removing the bed cartridge intact.

Ruthenium Monitor. Four ruthenium samplers and a single monitoring instrument are used to record the DFs across the pairs of primary and back-up adsorbers and the HEPA filter. The ruthenium samplers consist of small silica gel beds contained within NaI crystals such that a small gas sample is continuously drawn through the beds. The ruthenium-106 activity in the gas stream is continuously monitored by a multichannel analyzer that can also monitor other semivolatile fission products that may be present. Sequential switching is used to check the accumulative activity on each sampler at the desired frequency.

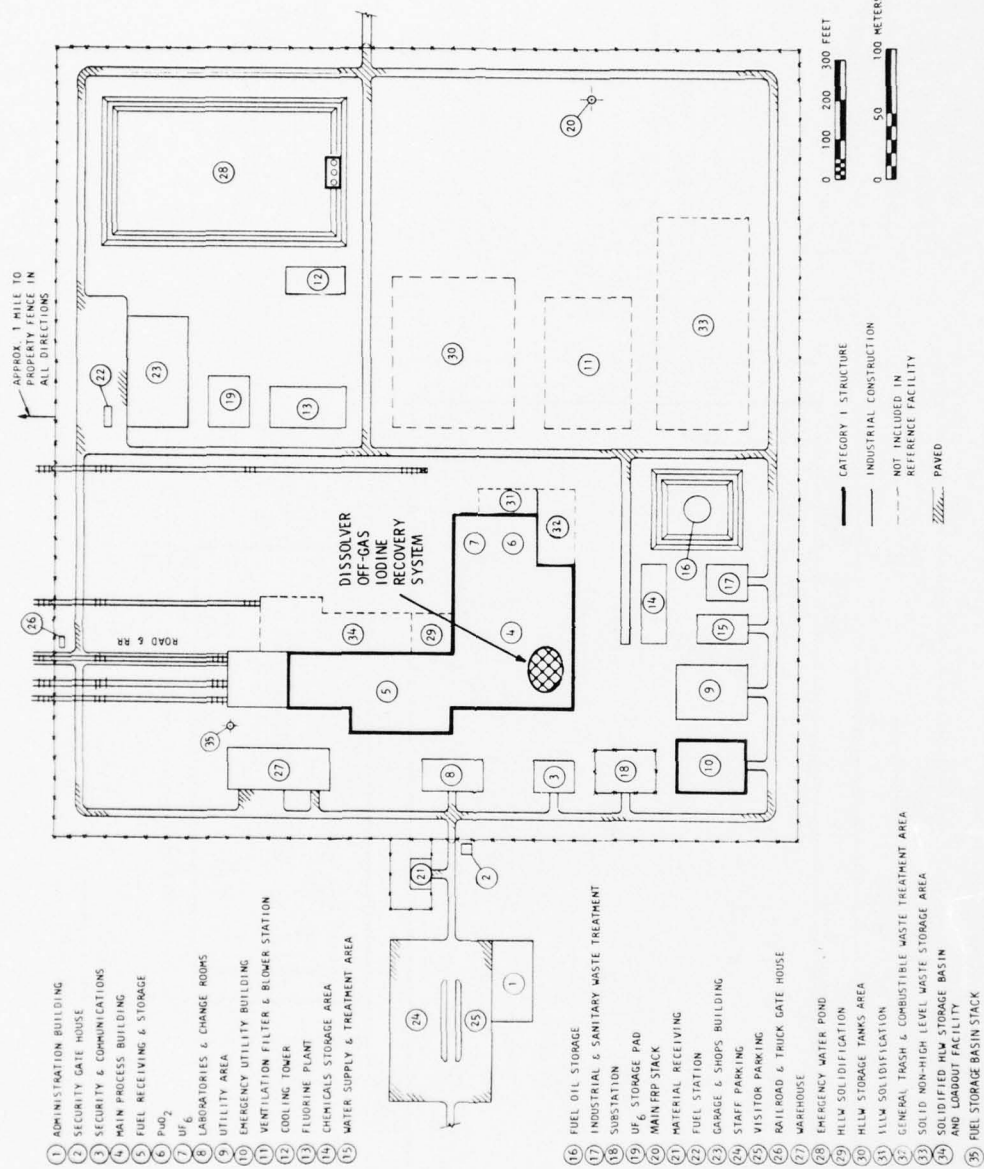


FIGURE 4.9.2. Location of the Dissolver Off-gas Iodine Recovery System Within the Fuel Reprocessing Plant

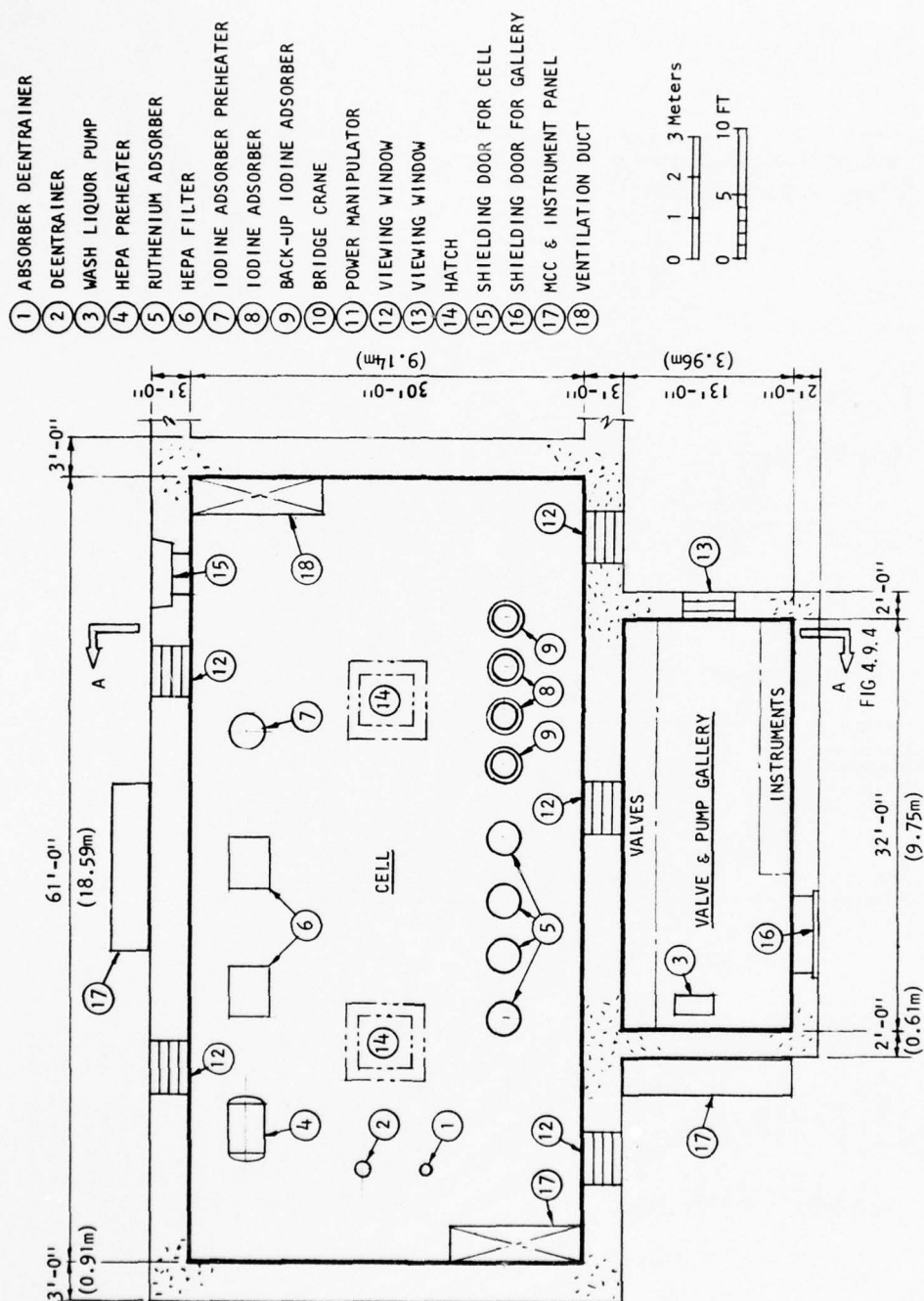


FIGURE 4.9.3. Dissolver Off-gas Iodine Recovery System, General Plan

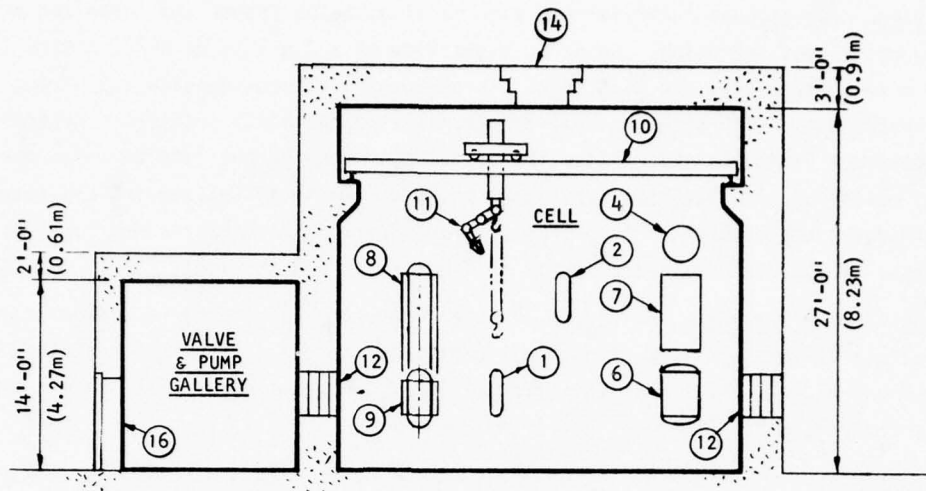


FIGURE 4.9.4. Dissolver Off-gas Iodine Recovery System, Cross-sectional View (Circled numbers refer to key in Figure 4.9.3.)

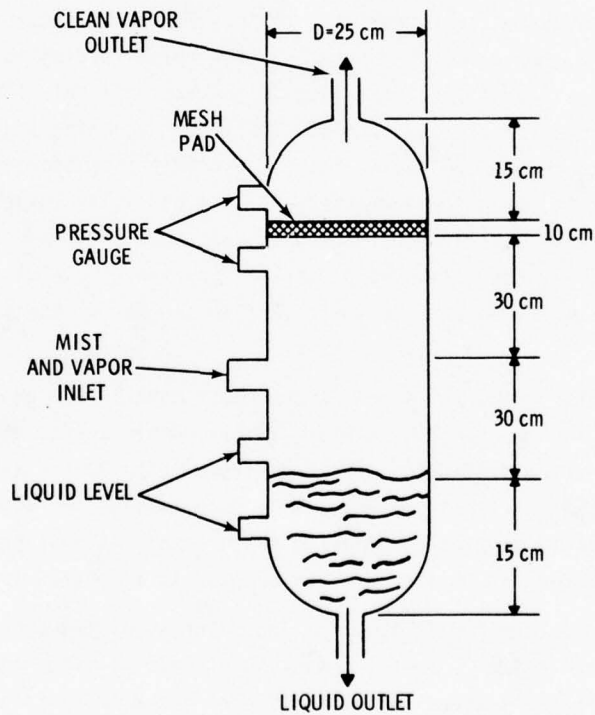


FIGURE 4.9.5. Iodine Recovery System Deentrainer

HEPA Filter. Two standard HEPA filters with metal-asbestos frames are installed parallel-wise to allow continuous operation. Based on a gas flow of $3.4 \text{ m}^3/\text{min}$ at 45°C , a size 3 HEPA ($0.3 \text{ m} \times 0.3 \text{ m}$ in surface area and 0.15 thick) is adequate (maximum capacity $4.3 \text{ m}^3/\text{min}$). The filters are instrumented with both pressure-differential and activity monitors. General operating experience indicates that filter change is determined by the rate at which the radioactivity builds up. Typical DOG service at the Idaho National Engineering Lab requires HEPA filter change every 6 months.⁽⁸⁾ A 2-month change period has been assumed for this facility because of the high ruthenium levels in light water reactor fuel.

Iodine Adsorber Preheater. The iodine adsorber preheater raises the gas temperature to 150°C using electrical heaters made of austenitic stainless steel. A nominal heat load of 6.8 kW is required and a design heater installation of 10 kW is recommended. The heater power is automatically controlled to give 150°C gas in the outlet.

Iodine Adsorbers. A typical iodine adsorber cartridge is illustrated in Figure 4.9.6, giving the dimensions of the adsorbent train filter cartridges. The adsorber, amorphous silicic acid impregnated with silver nitrate, is encapsulated in separate filter cartridges such that each cartridge can be readily inserted or removed from the filter train when instrumentation indicates that iodine breakthrough has occurred or a reprocessing campaign has ended. Figure 4.9.7 provides a schematic of the total train. Each filter cartridge, or adsorbent container, has a locking groove (see Figure 4.9.6) for ready loading and unloading of the adsorbent train vessels. Each filter cartridge weighs approximately 125 kg (275 lbs) and fits into standard 55-gal drums for storage or final isolation. Loading and unloading operations are required not only to remove the iodine-loaded cartridges for storage or isolation but also to maximize utilization of the adsorbent material. The partially-loaded bottom cartridge in the primary vessel and the normally unused back-up cartridge train are placed in the front first and second positions, respectively, of the primary vessel during each change operation. New cartridges are placed in the back-up vessel and in the bottom positions of the primary vessel.

Iodine Monitor. The iodine-129 samplers are positioned before and after the primary and back-up iodine adsorbers. The sampling systems involve small heated beds of silver-zeolite positioned on top of lithium-drifted germanium detectors (the 30 keV x-ray from ^{129}I is measured). A small sample stream is drawn continuously through the beds; however, the samplers must be evacuated to remove krypton-85 prior to measurement. A multichannel analyzer with sequential switching is used to monitor a given sampler at a desired frequency.

Shielding and Remote Handling Equipment. The major shielding consideration in the DOG iodine recovery facility is the $^{106}\text{Ru-Rh}$. Assuming a constant feed rate of 25 Ci/day to the ruthenium adsorber, in 5 years about $14,000 \text{ Ci}$ (97% of the steady-state level) would accumulate. About 1 m of concrete is adequate for shielding. The HEPA filter is installed in the shielded cell to allow for activity from $^{106}\text{Ru-Rh}$ ($\sim 95 \text{ Ci/yr}$), other particles, and ^{85}Kr .

The iodine adsorption beds (at saturation) would establish a dose rate of about 1 mR/hr . The activity of the gaseous fission products in the void spaces of the iodine adsorber during operation would contribute an additional activity. Therefore, the iodine beds are installed in the shielded cell.

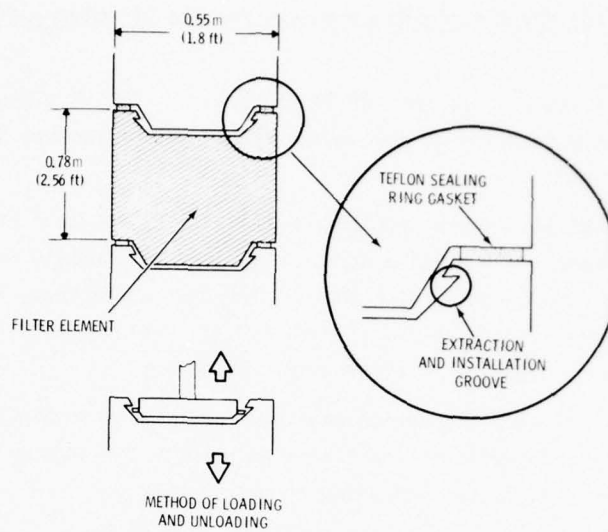


FIGURE 4.9.6. Typical Iodine Adsorber Cartridge

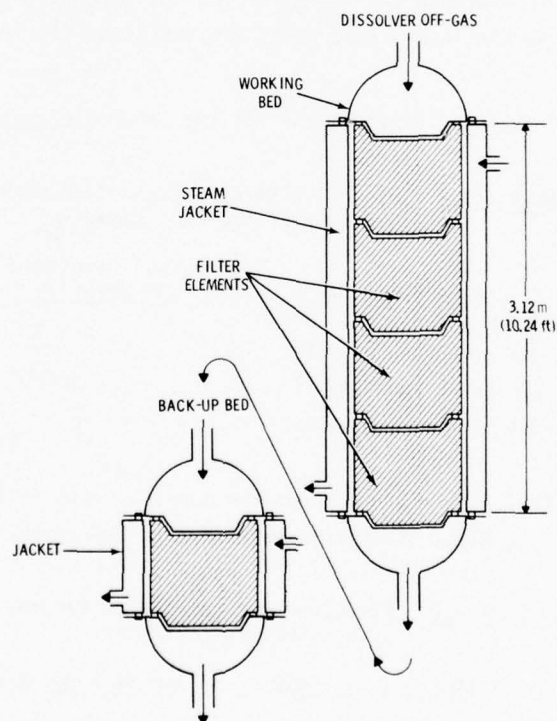


FIGURE 4.9.7. Iodine Adsorber Train

4.9.1.5 Operating and Maintenance Requirements for the Dissolver Off-gas Iodine Recovery System

The facility operates as part of the FRP 24 hours a day, 7 days a week, 300 days a year. Normal activities include monitoring of the iodine and ruthenium removal systems and normal maintenance and replacement.

All normal process operations are handled remotely in the hot cell and dose rates are limited to less than 1 mrem/hr. The valve and pump gallery is normally unoccupied; personnel enter only to install or remove equipment. Where infrequent operations, instrument readings, and some maintenance activities are needed (Figure 4.9.4), personnel may be exposed to higher dose rates. In such cases, exposure is rigorously controlled.

Maintenance of the ruthenium adsorption subsystem must be by remote handling equipment because of the high radiation levels in the silica gel beds. The iodine adsorbent is contained in cartridges that can be readily handled using an overhead crane.

During operation, the deentrainers occasionally plug (indicated by a mesh pad pressure drop of three times the nominal ΔP) and require washing with water or acid using the spray nozzles installed for that purpose. Both ruthenium and iodine adsorption beds are operated until breakthrough. At breakthrough the radiation monitors alarm, the gas flows are switched to the parallel system, and the loaded adsorbents are replaced with fresh adsorbent by using remote manipulators.

Staffing. Estimated staffing requirements for the reference system are shown in Table 4.9.4.

TABLE 4.9.4. Dissolver Off-gas Iodine Recovery System Staffing Requirements

<u>Job Description</u>	<u>Personnel Required, man-yr/yr</u>
Operators	1
Radiation monitors	0.5
Maintenance craftsmen	1

Supplies and Utilities. Table 4.9.5 shows the supplies used in the dissolver off-gas iodine recovery system. Estimates of utility requirements are shown in Table 4.9.6.

TABLE 4.9.5. Dissolver Off-gas Iodine Recovery System Supply Requirements

<u>Description</u>	<u>Use</u>	<u>Annual Requirement</u>
Silica gel	Ru recovery	0.5 m ³
Silver-zeolite	I ₂ recovery	6.6 m ³

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TABLE 4.9.6. Dissolver Off-gas Iodine Recovery System
Utility Requirements

Utility	Use Rate	Annual Requirement
Electricity	7 kW	5×10^4 kWh
Steam	42 kg/hr	3×10^5 kg

4.9.1.6 Secondary Radioactive Wastes for the Dissolver Off-gas Iodine Recovery System

Estimates of secondary radioactive wastes associated with the reference system are shown in Table 4.9.7.

TABLE 4.9.7. Dissolver Off-gas Iodine Recovery
System Secondary Radioactive Wastes

Description	Volume, m ³ /year	Radioactivity Factor ^(a)
Combustible and compactable waste	30	1×10^{-5}

a. Fraction of input activity (Table 4.9.1, volatiles excluded) in secondary wastes.

4.9.1.7 Emissions from the Dissolver Off-gas Iodine Recovery System

System emissions are characterized in Table 4.9.8.

TABLE 4.9.8. Dissolver Off-gas Iodine Recovery System Emissions

Emission	Description	Annual Quantity	Radioactivity Release Factor to Atmosphere ^(a)
Gaseous	Dissolver Off-gas	Air 1.3×10^6 m ³	³ H 0.2 ^(b)
			¹⁴ C 1.0
	NO _x	5.3×10^4 kg	⁸⁵ Kr 1.0
			¹²⁹ I 1×10^{-3}
			¹⁰⁶ Ru-Rh $5 \times 10^{-5(c)}$
	Minor accident integrated annual release		All others 1×10^{-9} Included in operational release

- a. Fraction of input activity (Table 4.9.1) released to atmosphere. Includes DF from main plant APS where applicable. Released over 300 days/yr. Peak release rates are approximately 10 times larger than the average rate.
- b. The remainder of the input tritium is removed in the scrubber deentrainer and is ultimately released to the atmosphere in the vaporized excess water.
- c. Assumes that the volatile ruthenium is not converted to particulate ruthenium by the time it reaches the APS.

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4.9.1.8 Decommissioning Considerations for the Dissolver Off-gas Iodine Recovery System

The dissolver off-gas iodine recovery system is designed to be functional for the life of the FRP. At the end of the reference FRP's operating life, the iodine recovery system is expected to be relatively free of external contamination. The capability to remove the silica gel, silver-zeolite, and HEPA filters facilitates decontamination.

4.9.1.9 Postulated Accidents for the Dissolver Off-gas Iodine Recovery System

Scenarios of postulated accidents for the dissolver off-gas iodine recovery system are listed in Tables 4.9.9 and 4.9.10. The loss of flow in either a ruthenium or iodine bed is considered a minor accident, with no activity released to the atmosphere. A torn HEPA filter could be isolated from the system for replacement and would not exceed normal operational releases through the FRP stack. No serious downstream contamination is anticipated from the postulated moderate accidents. No accident that could be classified as severe could be realistically postulated for this technology.

TABLE 4.9.9. Dissolver Off-gas Iodine Recovery System Minor Accidents

Accident No. and Description	Sequence of Events	Safety System	Release From Confinement
4.9.1 - Plugged iodine or ruthenium bed.	1. Bed plugged by particles.	1. Particle removal systems upstream of adsorber beds.	None.
	2. Loss of gas flow noted by instrumentation.	2. Radiation and airflow mon- itoring systems provide continuous information.	
	3. Adsorber is isolated from system.	3. The adsorber system has redundant system installed in parallel.	
	4. Dual system is switched into service.	4. The adsorber system is capable of being remotely replaced while in service.	
	5. Plugged bed is replaced.		
4.9.2 - Torn HEPA filter.	1. Filter media damaged because of improper installation or defective materials.	1. Filter DOP-tested before and after installation.	Would not exceed normal operational releases through FRP stack.
	2. Loss of filtration noted by alarm.	2. Radiation and airflow monitoring systems provide continuous information.	
	3. HEPA system is isolated from the rest of the system.	3. The ruthenium particle HEPA filter system is switched to the reserve system.	
	4. Dual system is switched into service	4. The defective HEPA can be replaced while the reserve system is in service.	
	5. Damaged filter is replaced while FRP is still in service.		

TABLE 4.9.10. Dissolver Off-gas Iodine Recovery System Moderate Accidents

Accident No. and Description	Sequence of Events	Safety System	Release From Confinement
4.9.3 - Process shut-down while dissolver is operating.	<ol style="list-style-type: none"> Both the iodine and ruthenium adsorber systems fail. Radiation and airflow monitoring systems detect venting of DOG directly to APS and FRP main stack. Dissolver and main FRP process are shutdown. DOG is shut down after processing material in dissolver or when safe conditions exist in the dissolver. FRP continues to process until out of dissolver feed. 	<ol style="list-style-type: none"> Radiation and airflow monitoring systems provide continuous information. DOG is shut down by reduction of temperature and acid concentration in the dissolver. FRP remains down until repairs are completed. 	<p>If the DOG is vented to the stack with a gas flow of about $2 \times 10^5 \text{ m}^3/\text{hr}$, the iodine release concentration would be $5.5 \times 10^{-8} \text{ } \mu\text{Ci}/\text{cm}^3$. This is below the maximum permissible concentration for soluble and insoluble species in air of 8×10^{-10} and $7 \times 10^{-8} \text{ } \mu\text{Ci}/\text{cm}^3$. Short-term releases would be considered to have small consequences.</p> <p>If ruthenium were also released to the APS under the conditions as above, the average release rate would be $3 \times 10^{-9} \text{ } \mu\text{Ci}/\text{cm}^3$. An additional DF of 10^4 could be assumed as the stream passed through the APS. This would then be below the controlled area guideline of a maximum permissible concentration for soluble and insoluble ^{106}Ru species in air of 8×10^{-8} and $6 \times 10^{-9} \text{ } \mu\text{Ci}/\text{cm}^3$.</p>
4.9.4 - Iodine canister adsorbent spill during replacement; expected frequency $3.6(0.01) = 0.036/\text{yr}$	<ol style="list-style-type: none"> Iodine canister ruptures during change. Spill detected by radiation monitoring system. Iodine system is placed in service. Solid adsorbent is vacuumed or swept into a spare canister. 	<ol style="list-style-type: none"> Radiation and airflow monitoring systems provide continuous information. Vacuum equipment is available in the event of a spill. Parallel iodine system provides continuous DOG recovery. 	None.
4.9.5 - Ruthenium canister adsorbent spill during replacement; expected frequency $2 \times 10^{-3}/\text{yr}$ (0.01 canisters broken per change; 0.2 canister changes per year).	<ol style="list-style-type: none"> Ruthenium canister ruptures during change. Spill detected by radiation monitoring system. Parallel ruthenium system is placed in service. Solid adsorbent is vacuumed or swept into a spare canister. 	<ol style="list-style-type: none"> Radiation monitoring and airflow systems provide continuous information. Vacuum equipment is available in the event of a spill. Parallel ruthenium system provides continuous DOG recovery. 	None.

4.9.1.10 Facility Costs for the Dissolver Off-gas Iodine Recovery System

Estimates have been made, in mid-1976 dollars, of capital, operating and leveled unit costs. A complete description of the cost estimate bases, assumptions and definitions is given in Section 3.8.

Capital Costs. The capital cost estimate for the iodine recovery facility is shown in Table 4.9.11 and covers all capital costs specifically resulting from the inclusion of the DOG facilities as an integral part of the primary reference FRP. These costs also cover incremental additions to heating, ventilation and air conditioning (HVAC) and utilities, as well as to bulk materials for piping, electrical and instrument tie-ins with the primary FRP. However, general FRP costs for such services as laboratories, personnel facilities, health physics support, warehousing, and shops are not allocated to the reference recovery system.

The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation.

TABLE 4.9.11. Dissolver Off-gas Iodine Recovery System Capital Cost Estimate

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		10	1,400	100	1,500
Buildings and structures		60	800	700	1,500
Bulk materials		80	1,300	1,000	2,300
Site improvements		10	--	100	100
Subtotal of direct site construction costs		160	3,500	1,900	5,400
Indirect site construction costs	40	30	700	900	1,600
Total field cost	40	190	4,200	2,800	7,000
Architect-engineering services					1,400
Subtotal					8,400
Owner's cost					2,600
Total facility cost					11,000
Estimate accuracy range					±30%

Operating Costs. Table 4.9.12 shows the operating cost components for the iodine recovery system. Direct labor is based on the manpower schedule in Table 4.9.4. Process materials and utilities costs are based on requirements shown in Tables 4.9.5 and 4.9.6. The silver-zeolite costs, based on an estimated price of \$110/kg, account for 70% of the total operating cost. This cost is subject to fluctuations in the price of silver. Annual maintenance materials costs are estimated at 3% of initial major equipment costs.

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TABLE 4.9.12. Operating Cost Estimate for the Dissolver Off-gas Iodine Recovery System

<u>Cost Element</u>	<u>Annual Costs, \$1000s</u>
Direct labor	54
Process materials	500
Utilities	5
Maintenance materials	45
Overhead	40
Miscellaneous	40
Total	660 $\pm 25\%$

Levelized Unit Costs. The total levelized unit cost, including levelized capital and operating costs, is given in Table 4.9.13. The cost calculation assumes private ownership of the facilities and a 15-year economic life.

TABLE 4.9.13. Levelized Unit Cost Estimate for the Dissolver Off-gas Iodine Recovery System

<u>Cost Element</u>	<u>Unit Cost, \$/kg HM</u>
Levelized capital charge	1.40
Levelized operating charge	.30
Levelized total unit cost	1.70 $\pm 40\%$

4.9.1.11 Facility Construction Requirements for the Dissolver Off-gas Iodine Recovery System

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating the impact of construction activities.

Project Schedules and Construction Manpower. The schedule for engineering, procurement and construction of the iodine recovery system is an integral factor of the overall schedule for the FRP. The field labor force estimated for the construction of the iodine recovery system is given below:

	<u>Man-hours, 1000s</u>
Manual field labor	190
Nonmanual field labor	40
Total field labor	230

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials and services provided at the site of the FRP, while offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is:

	Costs, \$1000s
Onsite	3,000
Offsite	8,000
Total	11,000

Site Requirements. The iodine recovery system shares the same site as the FRP. No site requirements beyond those for the FRP are identifiable. Commitments of land for the reference system are included with those of the FRP.

Water. Water used during the construction period is estimated at $2,600 \text{ m}^3$ (0.7×10^6 gal).

Construction Materials. Materials committed to construction of the recovery facility are:

Concrete	$1,150 \text{ m}^3$	(1,500 yd^3)
Steel	270 MT	(300 tons)
Copper	2.7 MT	(3 tons)
Zinc	negligible	
Aluminum	negligible	
Lumber	50 m^3	(20 MBFM)

Energy. Energy resources to be used during construction are:

Propane	26 m^3	(7,000 gal)
Diesel	265 m^3	(70,000 gal)
Gasoline	174 m^3	(46,000 gal)
Electricity		
Peak demand	200 kW	
Total consumption	130,000 kWh	

Transportation Requirements. No transportation requirements for the iodine recovery facility have been identified beyond those for the FRP.

4.9.1.12 Effects of Fuel Cycle Options

The reference process for the dissolver off-gas iodine recovery system assumes reprocessing of LWR fuel and recycling the retrieved uranium and plutonium. The following alternative fuel cycle modes have also been assessed insofar as they relate to this process.

No Recycle. Eliminating the fuel reprocessing operation eliminates the generation of dissolver and processing off-gases. Accordingly, no treatment system is required.

Uranium Recycle Only, with Plutonium to a Repository. This alternative is expected to generate about the same amount of dissolver and processing off-gas as in the uranium and plutonium case.

Uranium Recycle Only, with Plutonium to HLW. This alternative would generate about the same quantity of dissolver and processing off-gas as the uranium and plutonium recycle case.

4.9.2 Dissolver Off-gas Carbon-14 Recovery

Small quantities of carbon-14, released as carbon dioxide (CO_2) gas during spent fuel dissolution, are produced during fuel irradiation, primarily by a neutron reaction with the nitrogen-14 present in the fuel rods. Carbon-14 release is a concern because of the isotope's long half-life (5700 yr), and because it can be absorbed into the food chain through photosynthesis reactions. The low concentration of CO_2 in the dissolver off-gas (about 0.07 wt%) makes its recovery difficult. The carbon-14 content is 0.9 Ci ^{14}C per kg of CO_2 (approximately 0.08% of the CO_2 is $^{14}\text{CO}_2$). To date, no effort has been made to remove carbon-14 from FRP effluents even though procedures for CO_2 recovery from gas streams are used in the chemical industry.

4.9.2.1 Process Alternatives for Dissolver Off-gas Carbon-14 Recovery

One possible carbon-14 recovery process is CO_2 removal by caustic scrubbing to produce a soluble carbonate.⁽¹⁾ Two scrubbers are required to recover approximately 99% of the CO_2 . The addition of acid to the scrubber liquid releases the CO_2 to an air stream. The air- CO_2 gas is passed into a lime scrubber, which precipitates the CO_2 as CaCO_3 . The precipitated carbonate is filtered and dried for long term storage. Although the chemistry for this process is well-known, recovery of CO_2 has not been demonstrated with dissolved off-gas.

Another recovery process involves dissolution of CO_2 in fluorocarbons. The separated CO_2 is recovered as CaCO_3 . This method has demonstrated high-efficiency recovery on a pilot-plant scale at Oak Ridge but has not been demonstrated with actual dissolver off-gas.

The molecular sieve (zeolite) process was selected as the reference technology because of its compatibility with the cryogenic krypton removal process. Although moisture and CO_2 have been removed from gases by using several molecular sieves, removal has not yet been demonstrated for dissolver off-gas.

4.9.2.2 Design Basis for the Dissolver Off-gas Carbon-14 Recovery System

The following assumptions were made in the design of the reference system:

- The carbon-14 recovery system is designed to process the effluent gas from the DOG iodine recovery system to retrieve 99% of the carbon-14 (DF of 10^2) using molecular sieves.
- The molecular sieve process for carbon-14 removal requires high-efficiency removal of nitrogen oxides and water (a DF of 10^3 and 10^6 , respectively).
- The carbon-14 is recovered and packaged for disposal as calcium carbonate.

4.9.2.3 Dissolver Off-gas Carbon-14 Recovery Process

The dissolver off-gas from the iodine recovery system (Section 4.9.1) contains oxides of nitrogen, water vapor, tritium, and krypton. For efficient CO_2 removal, the oxides of nitrogen and the water vapor must first be removed from the stream. The krypton passes through the CO_2 removal system unaffected. The CO_2 is removed from the off-gas by molecular sieves. The processed gas is discharged to the APS or becomes a feed stream for the additional recovery of krypton. Periodically, the sieves are regenerated and the CO_2 is absorbed in a $\text{Ca}(\text{OH})_2$ scrubber, with the carbon-14 ultimately recovered as precipitated calcium carbonate (CaCO_3) by filtration.

The composition of the off-gas received from the iodine recovery system (Section 4.9.1) is shown in Table 4.9.14. Figure 4.9.8 is a process flow diagram for the carbon-14 recovery system; Table 4.9.15 gives the material balance. Table 4.9.16 describes the waste recovered from the reference process.

TABLE 4.9.14. Composition of Off-gas Entering Dissolver
Off-gas Carbon-14 Recovery System(a,b)

Component	Annual Quantity, kg	Radioactivity, Ci/yr	
		Fission Products	
H_2O	3.2×10^4	^3H	8.4×10^3
Air	1.6×10^6	^{129}I	6.9×10^{-2}
$\text{NO}_x(\text{c})$	5.3×10^4	^{85}Kr	1.68×10^7
CO_2	1.2×10^3	$^{90}\text{Sr} + ^{90}\text{Y}$	2.4×10^{-4}
		$^{95}\text{Zr} + ^{95}\text{Nb}$	2.2×10^{-5}
		$^{106}\text{Ru} + ^{106}\text{Rh}$	8.4
		$^{134}\text{Cs} + ^{137}\text{Cs} + ^{137\text{m}}\text{Ba}$	6.0×10^{-4}
		$^{144}\text{Ce} + ^{144}\text{Pr}$	9.6×10^{-4}
		All other	2.0×10^{-4}
		TOTAL	1.7×10^7
		Actinides	
		^{239}Pu	7.2×10^{-7}
		^{241}Pu	3.5×10^{-4}
		Other Pu	1.2×10^{-5}
		$^{242}\text{Cm} + ^{244}\text{Cm}$	3.4×10^{-5}
		All other	1.8×10^{-6}
		TOTAL	4.0×10^{-4}
		Activation Products	
		^{14}C	1.1×10^3

a. Based on Tables 4.9.1 and 4.9.8 without the APS contribution to the release factor.

b. Volume = $1.2 \times 10^6 \text{ m}^3/\text{yr}$.

c. Includes CO_2 in process air.

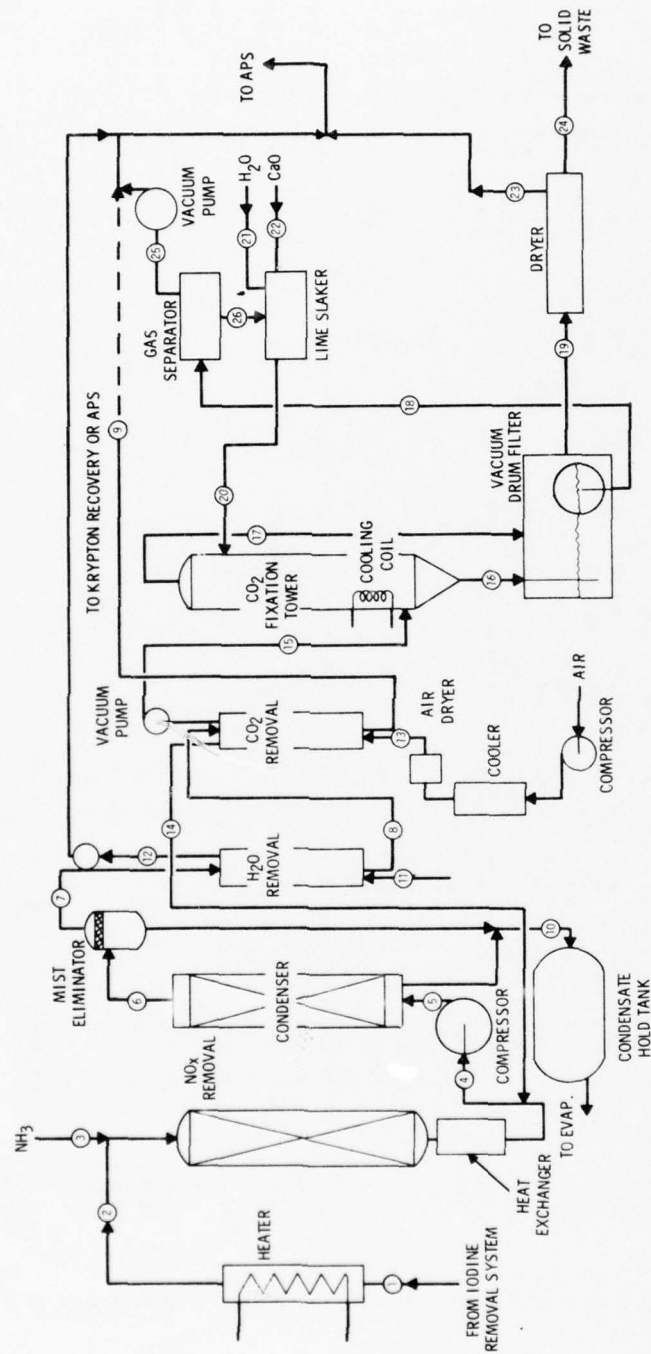


FIGURE 4.9.8. Process Flow Diagram for the Dissolver Off-gas Carbon-14 Recovery System (Circled numbers refer to stream numbers given in Table 4.9.15)

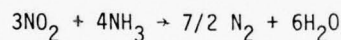
TABLE 4.9.16. Description of CaCO_3 Product from Carbon-14 Recovery System

Volume	$2 \text{ m}^3/\text{yr}$
Density	$1.3 \times 10^3 \text{ kg/m}^3$
Containers/yr 55-gal drums	10
Container Surface dose	$<0.01 \text{ mR/hr}$
Radioactivity as fraction of input (a)	$^{14}\text{C} \ 0.99$

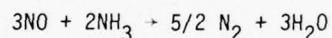
a. See Table 4.9.14.

The carbon recovery system is comprised of three basic subsystems: 1) NO_x removal subsystem, 2) H_2O removal subsystem, and 3) CO_2 removal subsystem.

NO_x Removal Subsystem. Figure 4.9.9 is a flow diagram of the NO_x removal subsystem. The gas from the iodine recovery system passes through an electric heater, which raises the gas temperature to about 350°C as required for operation of the NO_x removal system. The gas exits the heater and flows downward through a packed bed of synthetic mordenite. Near-stoichiometric amounts of ammonia are added to the gas stream just before it enters the bed. The synthetic mordenite bed catalyzes the reactions:



and



These reactions proceed essentially to completeness,⁽¹²⁾ and remove 99.9% of the NO_x . Minor quantities of N_2O are produced as a result of a competing reaction:

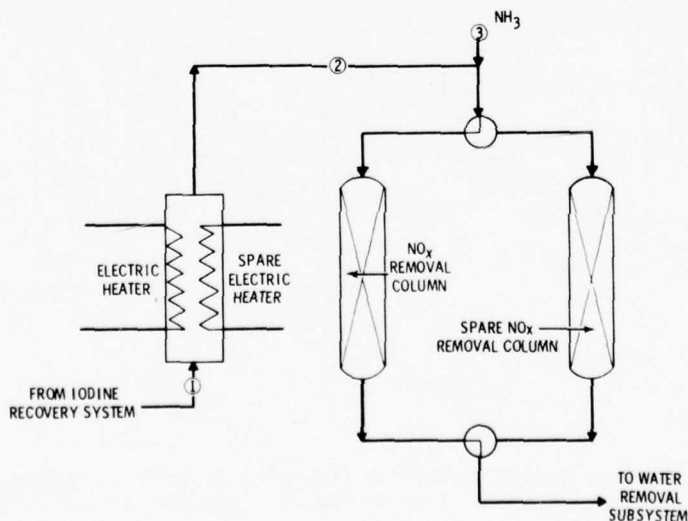
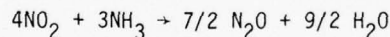


FIGURE 4.9.9. NO_x Removal Subsystem Flow Diagram (Circled numbers refer to stream numbers given in Figure 4.9.8 and Table 4.9.15)

which is dependent on temperature and the water content of the gas. By keeping the temperature at or above 350°C and the water content of the gas below 3%, less than 10% of the influent NO_2 should be converted to N_2O . None of the NO reacts to form N_2O .

The NO_x removal subsystem must operate whenever the dissolver is in operation. Spare heating coils are installed in the heater. If one set fails, the second set is automatically activated by a temperature sensor at the outlet of the heater. Two independently-piped NO_x reactors are available, with one in use, one as spare. A high pressure drop across one is sensed by a differential pressure sensor across the inlet and outlet of the bed and switches flow automatically to the second bed.

Water Removal Subsystem. Figure 4.9.10 is a flow diagram for the water removal subsystem. This system removes all but 1 ppm water vapor from the gas stream. After the NO_x removal subsystem, the gas is cooled to about 35°C in a heat exchanger and then compressed to 5 atm, which is the operating pressure required⁽¹³⁾ for efficient operation of the molecular sieves that remove water vapor and CO_2 .

Zeolite molecular sieves are natural or synthetic crystalline aluminosilicates with ion exchange properties. However, as ion exchangers they are of little importance. They are useful as highly specific sorbents. Because of their narrow, rigid, and useful pore structure (3-13Å) they act as "molecular sieves" which can sorb small molecules and completely exclude molecules which are larger than the openings in the crystal framework.

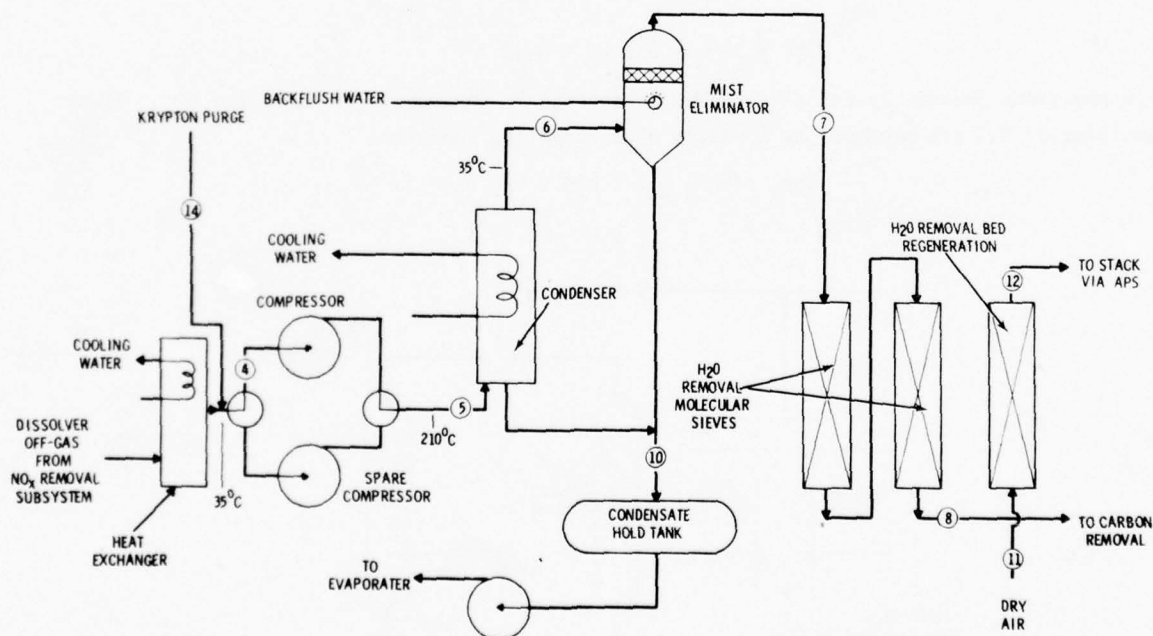


FIGURE 4.9.10. Water Removal Subsystem Flow Diagram (Circled numbers refer to stream numbers given in Figure 4.9.8 and Table 4.9.15)

Gas flow from the NO_x removal subsystem continuously passes through one of two compressors (one on line and one spare) to the condenser. The adsorption of water vapor and CO_2 on molecular sieves is a pressure and temperature dependent phenomenon. To operate at atmospheric pressure, either the temperature would have to be drastically reduced or the retention capabilities of the sieves markedly decreased.⁽¹³⁾ The compressor adds significant amounts of heat to the gas and increases its temperature to about 210°C . A cooler/condenser is used to reduce the gas temperature to 35°C for effective operation of the molecular sieve and to reduce the vapor loading in the sieve. The majority (85%) of the water vapor is condensed by the compression and cooling of the gas to the operating conditions required for the molecular sieves.

After the gas leaves the condenser it passes through a wire mesh demister to remove any entrained liquid. The condensate and entrained liquid flow via gravity to a condensate hold tank. The gas flows downward through two zeolite molecular sieves connected in series for water removal. (A third sieve is always available for regeneration).

An on-line hygrometer detects breakthrough of water vapor on the first sieve. The monitor leaves the system in this mode until equal concentrations of water are detected in both the influent and effluent streams of the first sieve. Meanwhile, the second bed in series has become partially loaded. When the hygrometer determines that the first bed is completely loaded, it sends a signal to a microprocessor which switches 16 two-position, 3- and 4-port valves, aligning the system such that the sieve originally second in the series is now first in series. The valving is set automatically to regenerate the first bed. When the second bed is fully loaded, the hygrometer signals the microprocessor to switch the valve alignment such that the #3 bed is now the first in series with the #1 bed. The #2 bed is automatically valved for regeneration.

The first step of regeneration, purging the molecular sieve vessel of krypton, is accomplished by a backflow of dry air (pressurized to keep the water adsorbed) routed back to just in front of the main compressor. After the purge is complete, the pressure on the bed is relieved. This pressure swing is sufficient to release most of the water adsorbed on the bed. However, to assure thorough removal of water from the vessel, a vacuum pump is automatically activated once the interior and exterior pressures equalize. This pump evacuates the vessel to 0.34 atm, and a controlled flow of $0.07 \text{ m}^3/\text{min}$ of dry air passes through the bed in the opposite direction of "loading" flow to flush out the last of the water. The gas contains minor quantities of tritium, but the major fraction of the tritium released from the dissolver is in the condensate hold tank in the form of HTO.

Carbon Dioxide Removal Subsystem. A flow diagram for the CO_2 removal subsystem is presented in Figure 4.9.11. This subsystem removes all but 3 ppm of the CO_2 in the gas stream by passing the gas at approximately 5 atm and 35°C through two zeolite molecular sieves connected in series. The gas, containing less than 1 ppm water vapor and less than 3 ppm CO_2 , leaves the CO_2 removal sieves and proceeds to the krypton removal system or to the atmospheric protection system (APS) and stack. Breakthrough is detected by monitors, and as with the sieves for water removal, the switching of beds is similarly accomplished by a microprocessor. Figure 4.9.12 details the process by which the sieves remove the CO_2 from the off-gas stream.

INFLUENT GAS

REGENERATION GAS INLET

1.

2.

3.

REGENERATION GAS OUT FLOW

EFFLUENT GAS STREAM

EFFLUENT GAS STREAM

REGENERATION GAS IN

1. PRIMARY
2. SECONDARY
3. REGENERATING

FIGURE 4.9.12a. Detail of Process by Which Molecular Sieves Remove Carbon Dioxide from Dissolver Off-gas

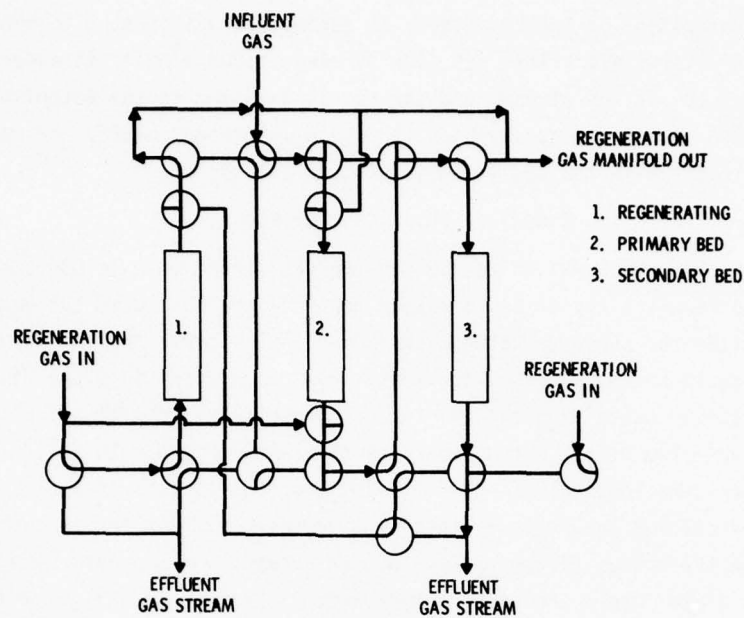


FIGURE 4.9.12b. Detail of Process by Which Molecular Sieves Remove Carbon Dioxide from Dissolver Off-gas

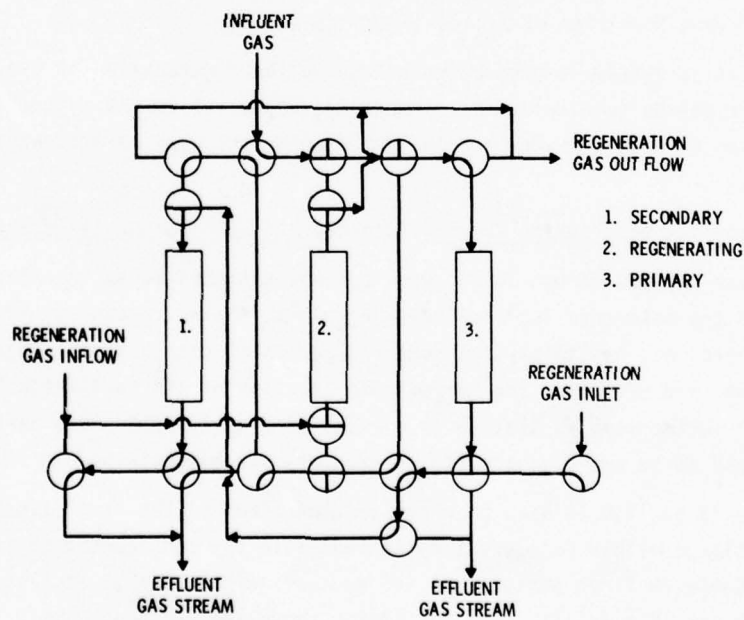
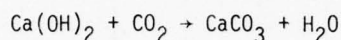


FIGURE 4.9.12c. Detail of Process by Which Molecular Sieves Remove Carbon Dioxide from Dissolver Off-gas

Although regeneration of the CO_2 sieves is accomplished according to the procedure described for the water sieves, less gas flow is used ($0.002 \text{ m}^3/\text{min}$) in order to maintain a high percentage of CO_2 in the stream, and the gas is diverted to the bottom of the CO_2 fixation tower. In the tower, the gas bubbles through a saturated solution of calcium hydroxide (Ca(OH)_2) which reacts with the CO_2 to form CaCO_3 as follows:



This reaction converts about 99% of the CO_2 in the gas stream to calcium carbonate (CaCO_3).⁽¹⁴⁾ The gas is vented from the top of the fixation tower to the hood over the vacuum drum filter in order to equalize the pressure between the CO_2 fixation tower and the vacuum filter, thus preventing the liquid in the CO_2 fixation tower from being drawn into the filter at an excessive rate. The liquid containing the calcium carbonate flows from the fixation tower through a continuous vacuum drum filter which separates the calcium carbonate solid from the liquid filtrate. The wet cake (60% solids - 40% liquid) proceeds to a dryer where the water is removed. The dry calcium carbonate is sent to a drumming station for preparation for disposal. The filtrate from the vacuum filter passes through a gas vapor separator and the liquid flows back to the lime slaker where the calcium hydroxide is prepared. The gas drawn through the vacuum pump via the vacuum filter from the fixation tower flows to the plant APS system and stack.

The CO_2 fixation tower is cooled by submerged tubes that circulate water at 32°C . Since Ca(OH)_2 solubility is an inverse function of temperature, the solution temperature must be kept below 35°C to prevent formation of solids in the tower.

The CO_2 fixation system is only operated during the regeneration of one of the CO_2 removal molecular sieves (generally eight hours per day). While the system is not in operation, the solution of calcium hydroxide is continuously recycled to prevent solid formation or plugging.

4.9.2.4 Facility Description for the Dissolver Off-Gas Carbon-14 Recovery System

The dissolver off-gas carbon-14 recovery system, designed to be incorporated as an integral part of the reference fuel reprocessing plant, shares common use of FRP services, utilities, laboratories, health physics support, personnel change areas, maintenance areas, warehousing, shops and offices. The approximate location of the facilities housing the reference system is the same as that shown earlier in Figure 4.9.2. The carbon-14 recovery system is designed to be added to the iodine recovery system described in Section 4.9.1.

Figures 4.9.13 and 4.9.14 show plan and section views of the facilities. All process equipment is enclosed within Category I cells and galleries constructed of reinforced concrete. Cells are provided with floor pans, sumps and protective coatings to facilitate decontamination and to cope with possible spills. The facilities shown are enclosed within the outer walls of the Category I FRP structure.

Major equipment items within the cells are described in Tables 4.9.17, 4.9.18 and 4.9.19.

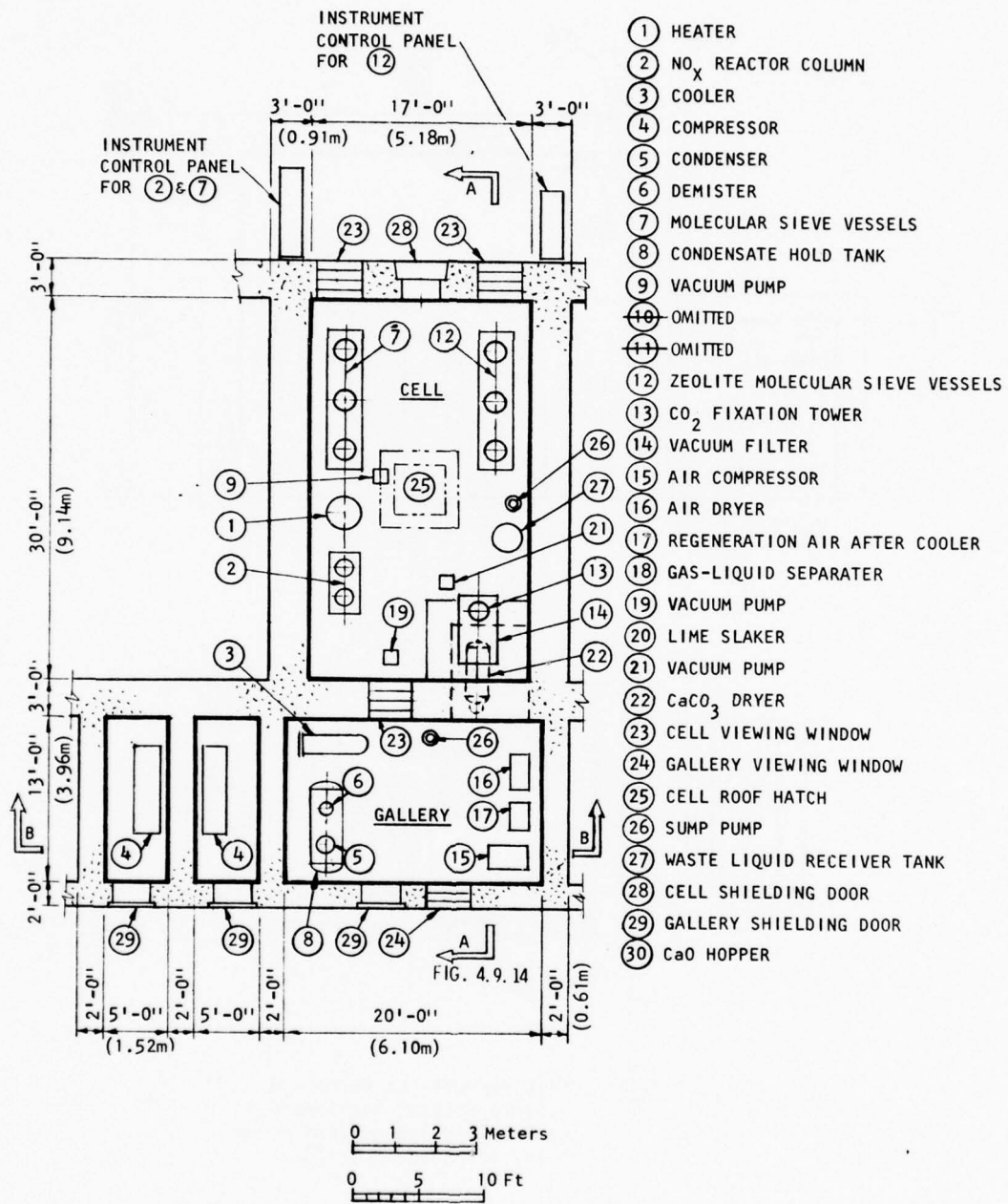


FIGURE 4.9.13. Dissolver Off-gas Carbon-14 Recovery System, General Plan

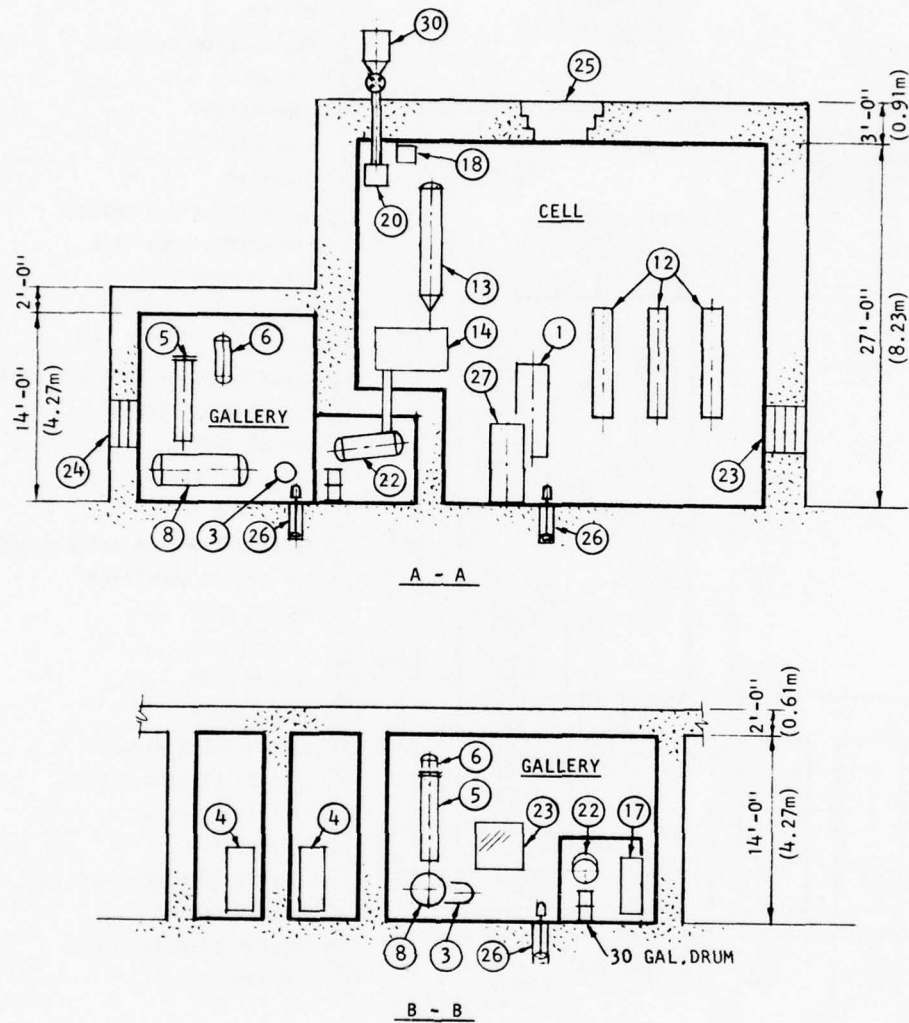


FIGURE 4.9.14. Dissolver Off-gas Carbon-14 Recovery System, Sections A-A and B-B (Circled numbers refer to key in Figure 4.9.13)

TABLE 4.9.17. NO_x Removal Subsystem Equipment

Equipment	Dimensions	Type	Capacity	Material Construction	Number Required
Heater (2 coils)		Electrical resistance	20 kW	304 SS	1
NO _x reactor	29 cm (ID) 92 cm (L)	Packed bed	0.6 m ³	304 SS	2

TABLE 4.9.18. Water Removal Subsystem Equipment

Items	Dimensions	Type	Capacity	Material Construction	Number Required
Cooler	244 cm (L) 32 cm (OD)	Single-pass turbulent flow; Gasside: Re = 15,000 126 tubes 1.6 cm (OD)		316 SS	1
Compressor		2-stage piston	Inlet = 0.75 atm Outlet = 5 atm 2.94 m ³ /min	316 SS	2
Condenser	244 cm (L) 32 cm (OD)	Shell-and-tube; single pass; 100 tubes	Shell side: H ₂ O @ 32°C Tube side: 2.94 m ³ /min q = 1350 cal/hr	316 SS	1
Demister	86 cm (L) 1110 cm (ID)	Wire mesh	2.94 m ³ /min	316 SS	1
Molecular Sieve vessels	210 cm (L) 38 cm (OD)	Zeolite	0.24 m ³	316 SS	3
Condensate hold tank	182 cm (L) 73 cm (D)	Pressure vessel rated to 7 atm		316 SS	1

TABLE 4.9.19. CO₂ Removal Subsystem Equipment

Items	Dimensions	Type	Capacity	Material	Number Required
Molecular sieve	38.1 cm (ID) 2.43 m (L)	Zeolite	2.94 m ³ /min	316 SS	3
CO ₂ fixation tower	61 cm (ID) 2.43 m (L)	Not applicable	Not applicable	316 SS	1
Vacuum filter		Drum	Slurry at 5 kg/hr	316 SS	1
Compressor			5.66 m ³ /min Discharge pressure = 5.1 atm Suction = 1 atm	316 SS	1
Cooler		Shell-and-tubes	420 kcal/hr	316 SS	1
Gas-liquid separator		Packed bed	10 l/min (1.42 m ³ /min)	316 SS	1
Vacuum pump			1.42 m ³ /min Discharge pressure = 1 atm Suction = 0.34 atm	316 SS	1
Lime slaker		Agitated tank	1200 l	316 SS	1

Shielding and Remote Handling Equipment. All operations are carried out inside shielded cells using remote controls and remote manipulation. The compressor and pump gallery is normally unoccupied; personnel enter only to install or remove equipment. Entry of personnel into the cell or gallery is rigorously controlled to minimize exposure to radiation and contamination hazards.

4.9.2.5 Operating and Maintenance Requirements for the Dissolver Off-gas Carbon-14 Recovery System

The facility operates as part of the FRP 24 hours a day, 7 days a week, 300 days of the year. Normal activities include monitoring the NO_x , H_2O , and CO_2 subsystems, and normal maintenance and replacement. All normal process operations are handled with remote equipment in the hot cell. Dose to personnel is controlled and limited to less than 1 mrem/hr. If plugging occurs in either of the packed-bed NO_x removal vessels, the vessels must be completely removed and replaced. This requires the use of flanges on the inlet and outlet of each bed. Burnt out electrical resistance elements in the heater must also be replaced during system shutdown.

Compressors are inherently high maintenance items, especially the 2-stage, piston type. Since regular maintenance is necessary, compressors must be located outside of the cell in a contamination control zone. An on-line spare is provided and can be automatically activated if the differential pressure sensor across the inlet and outlet registers a drastic pressure drop.

Backwash of the mist eliminator pad is automatically accomplished from below when a pre-determined unacceptable pressure drop develops across the pad.

Staffing. Estimated staffing requirements for the facility are shown in Table 4.9.20.

TABLE 4.9.20. Dissolver Off-gas Carbon-14 Recovery System Staffing Requirements

<u>Job Description</u>	<u>Personnel Required, man-yr/yr</u>
Operators	1
Radiation monitors	0.5
Maintenance craftsmen	0.5

Supplies and Utilities. Table 4.9.21 shows the supplies used for the DOG carbon-14 recovery system. Utility requirements are estimated in Table 4.9.22.

TABLE 4.9.21. Dissolver Off-gas Carbon-14 Recovery System Supply Requirements

<u>Supply</u>	<u>Use</u>	<u>Annual Requirement</u>
CaO	CO_2 fixation	1,450 kg
NH_3	NO_x removal	21,640 kg
Zeolite	CO_2 removal	0.8 m^3
Zeolite	NO_x removal	0.6 m^3
Zeolite	H_2O removal	0.75 m^3

TABLE 4.9.22. Dissolver Off-Gas Carbon-14 Recovery System Utility Requirements

<u>Utility</u>	<u>Use Rate</u>	<u>Annual Requirement</u>
Electricity	42 kW	3×10^5 kWh
Water consumed	0.08 m^3	550 m^3

Hazardous Materials. Calcium oxide can cause severe burns if it strikes the eyes, is ingested, or simultaneously contacts skin and water. Provision must be made to assure that calcium oxide will not be a physical contact hazard.

4.9.2.6 Secondary Radioactive Wastes for the Dissolver Off-gas Carbon-14 Recovery System

Estimates of secondary radioactive wastes associated with the reference facility are shown in Table 4.9.23.

TABLE 4.9.23. Dissolver Off-gas Carbon-14 Recovery System Secondary Radioactive Wastes

<u>Description</u>	<u>Volume, m^3/year</u>	<u>Radioactivity Factor^(a)</u>
Combustible and compactable waste	30	1×10^{-5}

a. Fraction of input activity (Table 4.9.14, volatiles excluded) in secondary wastes.

4.9.2.7 Emissions from the Dissolver Off-gas Carbon-14 Recovery System

Emissions for the reference system are characterized in Table 4.9.24.

4.9.2.8 Decommissioning Considerations for the Dissolver Off-gas Carbon-14 Recovery System

The dissolver off-gas carbon-14 recovery system is designed to be functional for the life of the FRP. At the end of the reference FRP's operating life, the carbon-14 recovery system would be relatively free of external contamination. The ability to remove the solid sorbents aids in decontamination. Ease of retirement and removal is an important consideration in selecting all materials and equipment for the facility.

4.9.2.9 Postulated Accidents for the Dissolver Off-gas Carbon-14 Recovery System

Scenarios of postulated accidents for the carbon-14 recovery system are given in Tables 4.9.25 and 4.9.26. No accident that could be classified as a severe accident could be realistically postulated for this technology.

TABLE 4.9.24. Dissolver Off-gas Carbon-14 Recovery System Emissions

Emission	Description	Annual Quantity	Radioactivity Release Factor to Atmosphere ^(a)
Gaseous	Dissolver off-gas	Air $1.3 \times 10^6 \text{ m}^3$	^3H 1.0 ^(b)
			^{14}C 1×10^{-2}
		NO_x $5.3 \times 10^1 \text{ kg}$	^{85}Kr 1.0
		N_2O $2.0 \times 10^3 \text{ kg}$	^{129}I 1.0
			$^{106}\text{Ru-Rh}$ 0.9 ^(c)
	Minor accident integrated annual release		All others 1×10^{-4}
Cooling tower water	<ul style="list-style-type: none"> • evaporated, T=38°C • drift, T=38°C • blowdown, T=27°C 	$4.7 \times 10^5 \text{ kg}$	Included in operational release
		$2.3 \times 10^3 \text{ kg}$	
		$8.2 \times 10^4 \text{ kg}$	
Other	Heat	$3.2 \times 10^2 \text{ MW-hr}$	
		$(1.0 \times 10^9 \text{ Btu})$	

- a. Fraction of input activity (Table 4.9.14) released to atmosphere. Includes DF from main plant APS where applicable. Released over 300 days/yr. Peak release rates are approximately 10 times larger than the average rate.
- b. Removed from dissolver off-gas but ultimately released via FRP excess water vaporizer.
- c. Assumes that the volatile ruthenium is not converted to particulate ruthenium by the time it reaches the APS.

TABLE 4.9.25. Dissolver Off-gas Carbon-14 Recovery System Minor Accidents

Accident No. and Description	Sequence of Events	Safety Systems	Release from Confinement
4.9.6 - Plugged recovery bed.	1. NO_x , H_2O , or CO_2 bed plugged by particles	1. Equipment upstream to control particulates.	None.
	2. Loss of gas flow noted by instrumentation.	2. Radiation and air flow monitoring systems provides continuous information.	
	3. Identified bed is isolated from system.	3. The adsorber and reactor systems have redundant units installed in parallel.	
	4. Dual system is switched into service.	4. The beds are capable of being remotely replaced while in service.	
	5. Plugged bed is replaced.		
4.9.7 - Plugged lime scrubber.	1. $\text{Ca}(\text{OH})_2$ forms a plug in a recirculation line to the CO_2 scrubber tower.	1. Solution recycled continuously to prevent plugging.	None.
	2. The release of pressure on the CO_2 removal bed is stopped and the pressure is increased to stop the release of CO_2 .	2. Monitoring systems detect a plug in the tower.	
	3. The two other beds continue to remove CO_2 (~16 hours).	3. The two other CO_2 removal units continue to collect CO_2 . The CO_2 fixation tower is only normally operated for 8-hr per day.	
	4. The plug in the CO_2 fixation tower is located and unplugged or bypassed.	4. Bypass lines are available if the plug cannot be located within 16 hours.	
		5. The calcium hydroxide can be dissolved out of the tower with water.	

4.9.37

TABLE 4.9.26. Dissolver Off-gas Carbon-14 Recovery System Moderate Accidents

Accident No. and Description	Sequence of Events	Safety Systems	Release from Confinement
4.9.8 - Process shutdown with ^{14}C venting.	<ol style="list-style-type: none"> Carbon-14 fixation system bypassed for 30 days due to process equipment failure. Dissolver and other volatile recovery systems continue (I, Ru, Kr, H_2O, NO_x) to operate. Equipment repaired and ^{14}C fixation resumed. 	<ol style="list-style-type: none"> System can collect ^{14}C for 16 hours before fixation system needed. Radiation and airflow sensors monitor venting of ^{14}C to the FRP main stack. Sample towers used to monitor for increased ^{14}C concentrations. 	If the DOG is vented directly to the stack, approximately 5 Ci of ^{14}C would be released per day. Since the current practice of releasing all airborne carbon is acceptable, short term releases in future reprocessing plants would be considered to have small consequences.

4.9.2.10 Facility Costs for the Dissolver Off-gas Carbon-14 Recovery System

The costs have been estimated for the dissolver off-gas carbon-14 recovery system at the FRP assuming it is operated in conjunction with the iodine recovery system (Section 4.9.1). A complete description of the cost estimate bases, assumptions and definitions is given in Section 3.8.

Capital Costs. The capital cost estimate for the carbon-14 recovery facility is shown in Table 4.9.27, expressed in mid-1976 dollars. This estimate covers all capital costs specifically resulting from the inclusion of the carbon-14 recovery facility as an integral part of the reference FRP. Capital costs also cover incremental additions to heating, ventilation, and air conditioning (HVAC) and utilities, as well as bulk materials for piping, electrical and instrument tie-ins with the primary FRP. However, general FRP costs for such services as laboratories, personnel facilities, health physics support, warehousing, shops, and administration facilities are not allocated to the reference system.

TABLE 4.9.27. Capital Cost Estimate for the Dissolver Off-gas Carbon-14 Recovery System

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		10	800	100	900
Buildings and structures		30	400	400	800
Bulk materials		60	1,000	700	1,700
Site improvements		10	--	100	100
Subtotal of direct site construction costs		110	2,200	1,300	3,500
Indirect site construction costs	30	20	500	600	1,100
Total field cost	30	130	2,700	1,900	4,600
Architect-engineering services					900
Subtotal					5,500
Owner's cost					1,500
Total facility cost					7,000
Estimate accuracy range					±30%

Operating Costs. The operating cost components for the DOG carbon-14 recovery system are shown in Table 4.9.28. The direct labor costs are based on the manpower requirements given in Table 4.9.20. Process materials and utilities costs are derived from requirements shown in Tables 4.9.21 and 4.9.22. Annual maintenance materials costs were estimated at 2% of initial major equipment cost. Overhead and miscellaneous costs were calculated as described in Section 3.8.

TABLE 4.9.28. Operating Cost Estimate for the Dissolver Off-gas Carbon-14 Recovery System

Cost Element	Annual Costs, \$1000s
Direct labor	30
Process materials	15
Utilities	10
Maintenance materials	20
Overhead	25
Miscellaneous	10
Total	110 + 50% - 25%

Levelized Unit Costs. Table 4.9.29 gives the total levelized unit cost, including the levelized capital and operating components. The cost calculation assumes private ownership of the facilities and a 15-year economic life.

TABLE 4.9.29. Levelized Unit Cost Estimate for the Dissolver Off-gas Carbon-14 Recovery System

Cost Element	Unit Cost, \$/kg HM
Levelized capital charge	0.94
Levelized operating charge	0.06
Levelized total unit cost	1.00 ± 40%

4.9.2.11 Facility Construction Requirements for the Dissolver Off-gas Carbon-14 Recovery System

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area.

Project Schedules and Construction Manpower. The schedule for engineering, procurement and construction of facilities for carbon-14 recovery is an integral factor in the overall schedule for the FRP. The field labor force estimated for the construction of the carbon-14 recovery system is given below:

4.9.39

	Man-hours, 1000s
Manual field labor	130
Nonmanual field labor	30
Total field labor	160

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials and services provided at the site of the FRP, while offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is as shown:

	Costs, \$1000s
Onsite	2,000
Offsite	5,000
Total	7,000

Site Requirements. The carbon-14 recovery facility shares the same site as the FRP. No additional site requirements beyond those for the FRP are identifiable. Commitments of land for the carbon-14 recovery facility are included with those of the FRP.

Water. Water to be used during the construction period is estimated at 1,900 m³ (0.5 x 10⁶ gal).

Construction Materials. Materials committed to the facility construction are:

Concrete	690 m ³	(900 yd ³)
All Steel	160 MT	(180 tons)
Copper	1.8 MT	(2 tons)
Zinc	negligible	
Aluminum	negligible	
Lumber	20 m ³	(10 MBFM)

Energy. Resources of energy expected to be used during construction:

Propane	19 m ³	(5,000 gal)
Diesel	189 m ³	(50,000 gal)
Gasoline	121 m ³	(32,000 gal)
Electricity		
Peak demand		150 kW
Total consumption		90,000 kWh

Transportation Requirements. No transportation requirements for the carbon-14 recovery system have been identified beyond those for the FRP.

4.9.2.12. Effects of Fuel Cycle Options

The reference process for dissolver off-gas carbon-14 recovery assumes reprocessing of LWR fuel and recycling the retrieved uranium and plutonium. The following alternative fuel cycle modes have also been assessed insofar as they relate to this process.

No Recycle. Eliminating the fuel reprocessing operation eliminates the generation of dissolver and processing off-gases. Accordingly, no treatment system is required.

Uranium Recycle Only, with Plutonium to Storage. This alternative is expected to generate about the same amount of dissolver and process off-gas as in the uranium and plutonium recycle case.

Uranium Recycle Only, with Plutonium to HLW. This alternative would generate about the same quantity of dissolver and process off-gas as in the uranium and plutonium recycle case.

4.9.3 Dissolver Off-gas Krypton Recovery

Both stable and radioactive krypton isotopes are produced as fission products during fuel irradiation and are released during spent fuel dissolution. About 0.04 wt% of the dissolver off-gas is krypton. At the time of reprocessing, the only radioactive krypton isotope remaining is krypton-85, which makes up about 6% of the total krypton. This isotope has a half-life of 10.7 yr and emits a medium-intensity beta radiation (0.65 MeV). Since krypton is a chemically inert gas, radiation hazard from its release results only from external exposure or an immersion dose. The only body organ appreciably affected is the skin. The principal concern with krypton-85 is for the possible long-term, worldwide accumulation in the atmosphere.

4.9.3.1 Process Alternatives for Dissolver Off-gas Krypton Recovery

Absorption by liquid fluorocarbons has not been demonstrated for removing krypton from the off-gas of a commercial fuel reprocessing plant (FRP). The presence of impurities such as nitrogen oxides (NO_x), H_2O and CO_2 is also a problem. Pilot-plant development of the process has been in progress at the Oak Ridge Gaseous Diffusion Plant since 1968. The fluorocarbon process has also been studied for use in the Allied-General Nuclear Services and Nuclear Fuels Services fuel reprocessing plants.

The use of cryogenic separation of the noble gases from dissolver off-gas was selected as the reference process for this report because all of the components of the process have been used extensively in commercial liquid air plants. In addition, a cryogenic distillation process has been operated intermittently at the Idaho Chemical Processing Plant to recover krypton-85 from fuel reprocessing off-gas for research and development applications.

An alternative to krypton recovery is dispersal to the atmosphere.

4.9.3.2 Design Basis for the Dissolver Off-gas Krypton Recovery System

The following assumptions were made in the design of the reference system:

- The krypton recovery system is designed to process the effluent gas from the dissolver off-gas (DOG) iodine recovery system for recovery of 90% of the krypton in pressurized gas cylinders using a cryogenic distillation process.
- The krypton storage cylinders are filled to a 34 atm pressure and contain 104,000 Ci of krypton-85. Approximately 145 cylinders are filled each year.
- The krypton recovery facility sends 10% of the krypton-85 to the FRP stack as an operational release.

4.9.41

4.9.3.3 Dissolver Off-gas Krypton Recovery Process

The dissolver off-gas from the iodine recovery facility (Section 4.9.1) contains oxides of nitrogen, water vapor, including tritium from the dissolver, and krypton. For efficient krypton removal, the oxides of nitrogen, and the carbon dioxide must first be removed from the stream. This part of the krypton recovery process is identical to the first part of the carbon-14 recovery process and is described in Section 4.9.2. (Figure 4.9.8 and Table 4.9.15, up through stream 15, give the flow diagram and material balance for the NO_x and CO_2 removal process.) The processed gas is then sent to the krypton recovery system, stream 9.

The composition of the off-gas received from the iodine recovery system is described in Table 4.9.14. (Stream No. 9 in Table 4.9.15, Section 4.9.2, is the feed stream to the krypton recovery system.) Figure 4.9.15 is a flow diagram for the krypton recovery system and Table 4.9.30 gives the material balance. The krypton gas produced from this system is described in Table 4.9.31.

Following NO_x and CO_2 removal, the oxygen in the off-gas is removed by converting it to water in a catalytic recombiner that uses hydrogen supplied by an electrolytic generator. Oxygen is present in the gas stream at its concentration levels in air. Although a cryogenic noble gas recovery system can be operated in an oxygen rich mode, as has been demonstrated at Idaho Chemical Processing Plant (ICPP), the advantages of an oxygen free system outweigh disadvantages if removal can be safely and efficiently accomplished. Catalytic (platinum or palladium) recombiners can be expected to reduce oxygen content by reaction with hydrogen to less than 0.01% by volume in the exit gas. The water that is produced in the recombiner is condensed. Part of the exit gas stream is recycled to the combiner inlet and mixed with feed gas and hydrogen in proportions such that mixed gas always contains less than 3% hydrogen by volume. (The minimum hydrogen concentration for an explosive mixture is 4%)

Oxygen-free gas leaves the recombiner circuit at about 480°C and passes to a primary condenser where it is cooled to 38°C and some of the water is removed. After leaving the primary condenser, the off-gas (now a mixture of nitrogen, noble gases, some water and hydrogen and trace quantities of nitrogen oxides) is passed through a secondary refrigerated condenser to remove additional water to a dew point of about 2°C. Exit gas from this condenser is compressed to approximately 2.4 atmospheres and passed through a demister to remove any droplets of free water picked up from the water-sealed compressors. Gas leaving the demister can be expected to contain about 0.005 kg of water per kg of dry gas. To keep the freeze out burden in the precoolers as low as possible, process gas is routed through a multiple-bed, silica-gel adsorbent dryer to reduce the gas dew point to -46°C (equivalent to 0.0002 kg of water/kg of dry gas). The gas then enters the cryogenic absorption, stripping, distillation, and recovery system.

The cryogenic system comprises precoolers, a primary absorption-stripping column, an argon-nitrogen stripping column and a final product fractionation column.

The precoolers cool the feed gas from -4°C to -160°C and warm the primary column exit gas from -184°C to approximately -12°C.

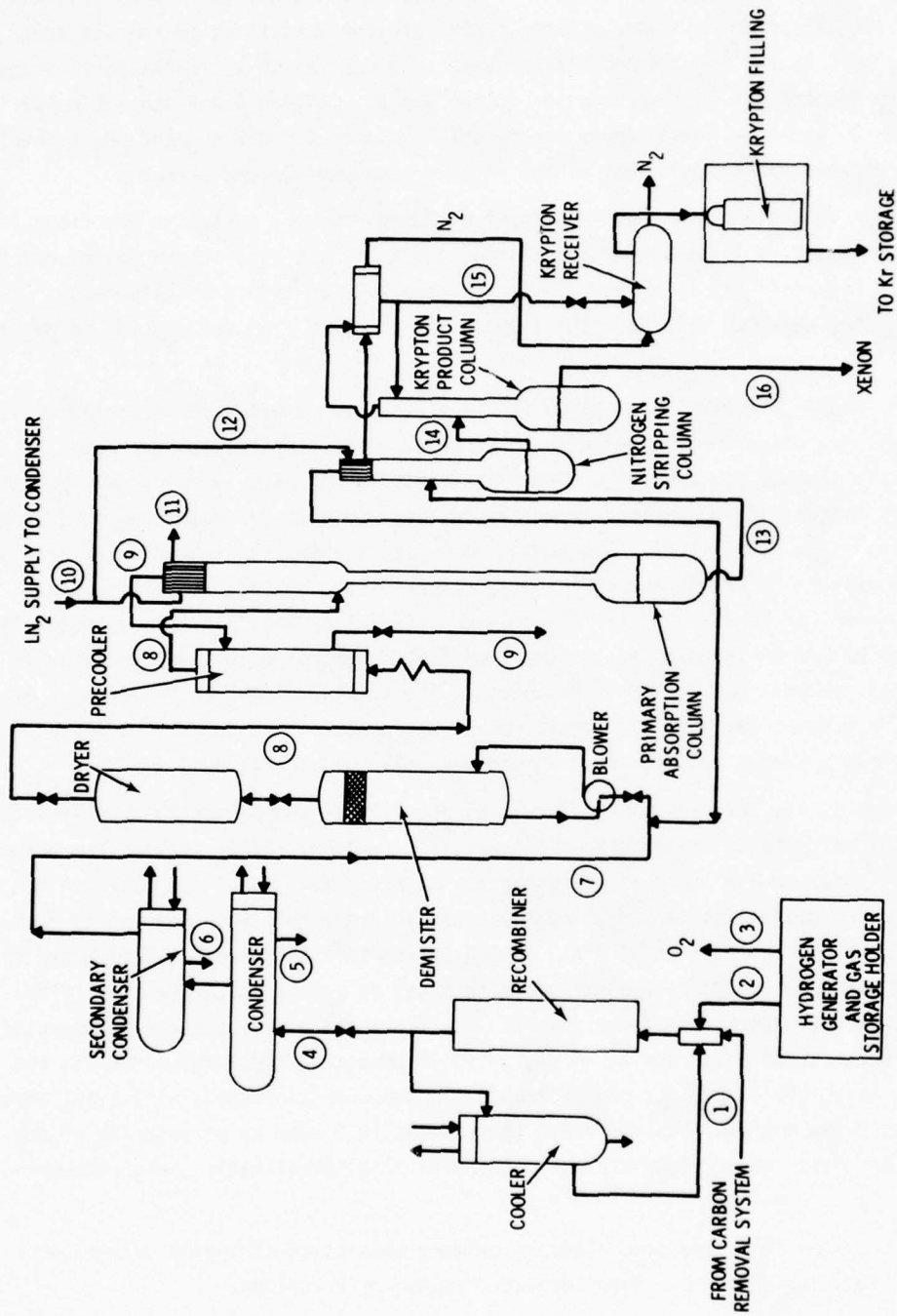


FIGURE 4.9.15. Process Flowsheet for the Dissolver Off-gas Krypton Recovery System After the Removal of Oxides of Nitrogen and Carbon Dioxide from the Feed Stream (Small circled numbers refer to stream numbers given in Table 4.9.30)

TABLE 4.9.30. Material Balance for the Krypton Recovery System

Stream Number	Description	Total Flow, kg/hr	Flow by Component, kg/hr											
			N ₂	O ₂	Ar	CO ₂	H ₂ O	NO _x	N ₂ O	I ₂	Br ₂	Kr	Xe	H ₂
1	Process gas feed (stream 9, Table 4.9.15)	225	171	50.8	2.78	3.8 x 10 ⁻⁴	5.28 x 10 ⁻⁶	7.4 x 10 ⁻³	2.81 x 10 ⁻¹	6.5 x 10 ⁻⁵	3.8 x 10 ⁻⁶	9 x 10 ⁻²	1.3	1.4 x 10 ⁻²
2	Hydrogen production	--	--	--	--	--	--	--	--	--	--	--	--	6.4
3	Waste oxygen	--	--	51.2	--	--	--	--	--	--	--	--	--	--
4	O ₂ free process gas	232	172	Trace	2.78	Trace	57.2	Trace	Trace	--	--	9 x 10 ⁻²	1.3	1.1 x 10 ⁻¹
5	Condensed H ₂ O	--	--	--	--	--	50.0	--	--	--	--	--	--	--
6	Condensed H ₂ O	--	--	--	--	--	6.6	--	--	--	--	--	--	--
7	Low H ₂ O process gas	232	172	Trace	2.78	--	0.7	Trace	Trace	--	--	9 x 10 ⁻²	1.3	1.1 x 10 ⁻¹
8	Dried process gas	232	172	Trace	2.78	--	0.009	Trace	Trace	--	--	9 x 10 ⁻²	1.3	1.1 x 10 ⁻¹
9	Cold stripped process gas	221	162	--	2.78	--	--	--	--	--	--	Trace	--	1.1 x 10 ⁻¹
10	LN ₂ supply total	60	60	--	--	--	--	--	--	--	--	--	--	--
11	Cold nitrogen gas	58	58	--	--	--	--	--	--	--	--	--	--	--
12	LN ₂ to N ₂ column reflux condenser	2.5	2.5	--	--	--	--	--	--	--	--	--	--	--
13	Feed to N ₂ strip column	11.3	9.9	--	--	--	--	--	--	--	--	9 x 10 ⁻²	1.3	--
14	Feed to Kr-Xe fractionation column	1.39	--	--	--	--	--	--	--	--	--	9 x 10 ⁻²	1.3	--
15	Kr product	--	--	--	--	--	--	--	--	--	--	8.1 x 10 ⁻²	2.0 x 10 ⁻²	--
16	Xe stream	--	--	--	--	--	--	--	--	--	--	9 x 10 ⁻³	1.28	--

TABLE 4.9.31. Description of Packaged Waste from the Krypton Recovery System

Volume (compressed gas)	6.2 m ³ /yr
Containers/yr (42.5-l gas cylinders)	145
Radioactivity as fraction of input	⁸⁵ Kr 0.9
Radioactivity per cylinder	104 kCi ⁸⁵ Kr
Heat per cylinder	150 W
Container surface dose rate	700 R/hr

Krypton and xenon in the feed gas are absorbed-condensed in the primary column by liquid nitrogen flowing downward through sieve plates. Liquid nitrogen (LN₂) is not fed directly to the top of the column. Instead, nitrogen in the off-gas stream is condensed by a reflux condenser at the top of the column. Purchased LN₂ is boiled inside the reflux condenser to absorb not only the heat necessary to liquify nitrogen within the column, but also to absorb column reboil heat, cold box heat leaks, conduction heat leaks, and recovery system reboil heat. A closed system is used to avoid the possibility of oxygen contamination of the process gas (commercial LN₂ may contain ~0.5% O₂/l).

The liquid nitrogen reflux in the primary column tower condenses and absorbs noble gases in the feed that have boiling points above argon. Hydrogen, nitrogen and most of the argon in the feed, with possible trace quantities of krypton, leave the top of the column. Xenon, krypton, nitrogen and some argon accumulate in the reboiler at the bottom of the absorption column.

The bottoms from the primary column can be distilled continuously or in batches. Available data indicate that a continuous fractionation system is feasible and could have some advantages. A continuous fractionation system has been selected for the reference krypton recovery system. Primary-column bottoms from the reboiler flow to an argon-nitrogen stripping column. Overheads from this column, mostly nitrogen with some argon and some krypton, are recycled to recover krypton. Bottoms consisting almost entirely of krypton and xenon flow to a krypton-xenon separation column. It should be possible to produce a high krypton overhead product and a xenon bottoms with essentially no krypton. However, it is conservatively assumed that the final krypton product is approximately 80% krypton and 20% xenon. Krypton recovery is assumed to be 90%.

Two receivers are provided for collecting the liquid krypton product. While one receiver is collecting product, the other one is used to fill storage cylinders. The product receivers store the krypton in amounts requiring cooling to remove decay heat. A receiver storing production equivalent to one 42.5 l cylinder of gas at 35 atm generates approximately 150 W in decay heat. The receivers are cooled with gaseous nitrogen at -193°C from the reflux condensers.

Krypton final storage cylinders are filled in a hot cell filling station by warming a krypton receiver to approximately -84°C . The product bottle is positioned at the filling station and is connected to the filling line. Line and bottle are evacuated before filling. After filling, the bottle is isolated and the fill line evacuated back to the process. The cylinders containing up to 104,000 Ci of krypton-85 at 35 atm are placed in an interplant-transfer shielded container and sent to the krypton storage facility (see Section 5.6) for 50 years of storage prior to release to the atmosphere.

4.9.3.4 Facility Description for the Dissolver Off-gas Krypton Recovery System

The dissolver off-gas krypton recovery system, designed to be incorporated as an integral part of the reference fuel reprocessing plant, (FRP) shares common use of FRP services, utilities, laboratories, health physics support, operating personnel change areas, maintenance areas, warehousing, shops and offices. The off-gas treatment system has sufficient capacity to handle the total dissolver off-gas (DOG) stream from the reference FRP. The approximate location of the krypton recovery facility is the same as that shown for iodine recovery in Figure 4.9.2. The krypton recovery system is designed to be added to the iodine recovery system (see Section 4.9.1). A plan and section view of the reference facility is shown in Figures 4.9.16 and 4.9.17. The facility for removing CO_2 , NO_x and H_2O from the incoming DOG is shown in Figures 4.9.18 and 4.9.19.

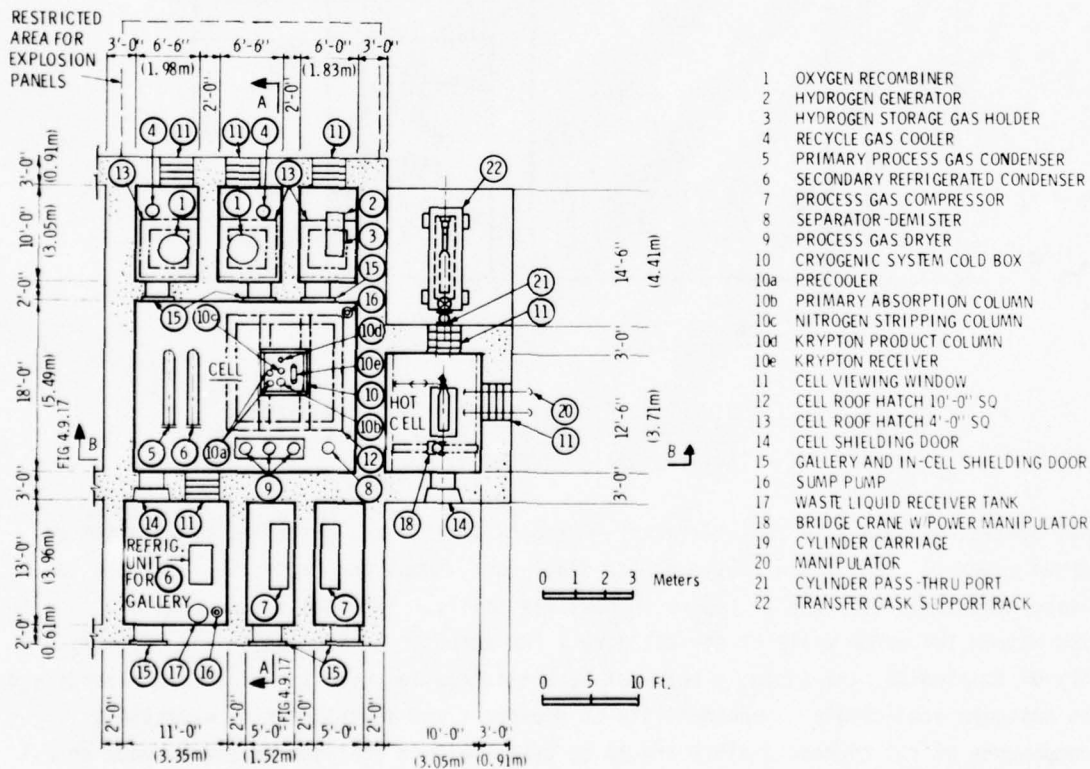


FIGURE 4.9.16. Dissolver Off-gas Krypton Recovery System, General Plan

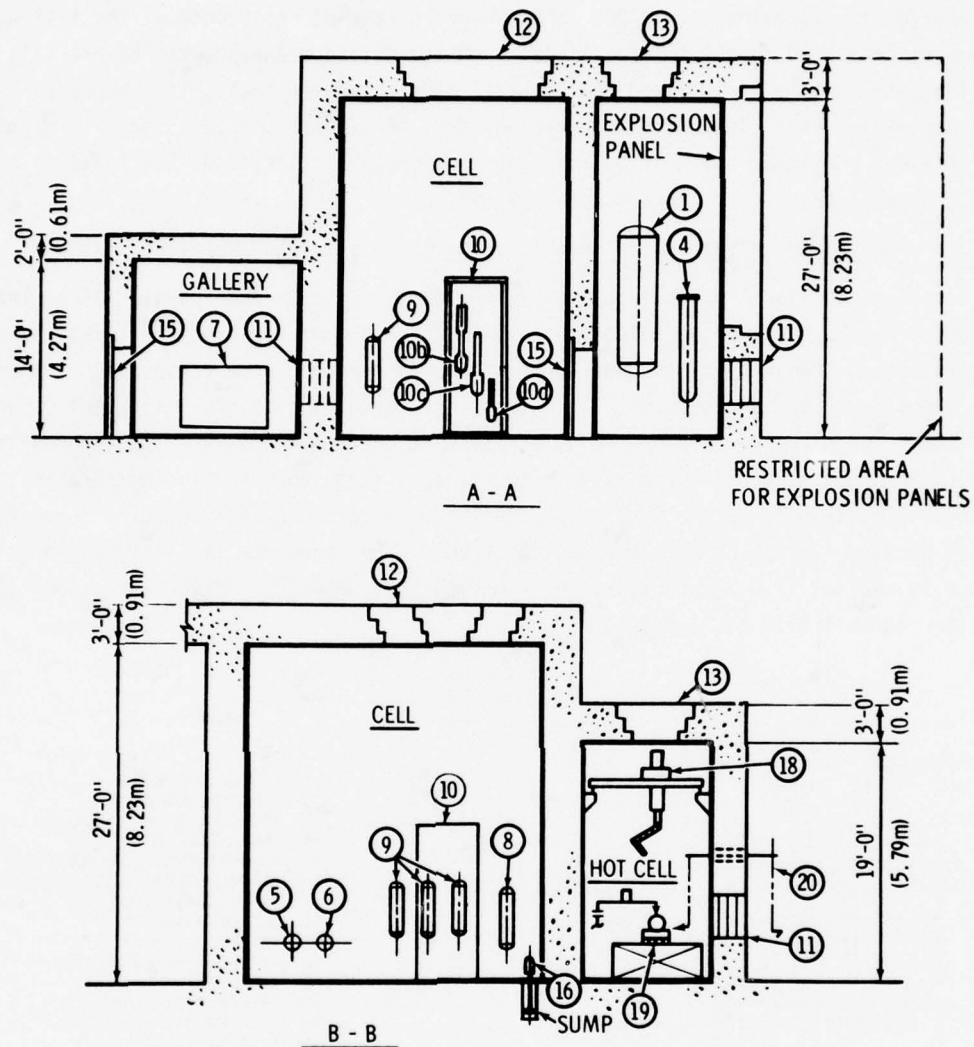


FIGURE 4.9.17. Dissolver Off-gas Krypton Recovery System, Sections A-A and B-B (See Figure 4.9.16 for key to circled numbers)

All process equipment is enclosed within Category I cells and galleries constructed of reinforced concrete. Cells are provided with floor pans, sumps and protective coatings to facilitate decontamination and to cope with possible spills. The facilities shown are enclosed within the outer walls of the Category I FRP structure. Because of the quantity and activity of krypton-85, the entire plant must be considered to present radioactive hazards and must be designed accordingly. Dependability of equipment and accessories is essential; only components of the highest quality are to be used, failure analyses should be made on all equipment and accessory items, and redundancy should be provided in areas of significant failure probability.

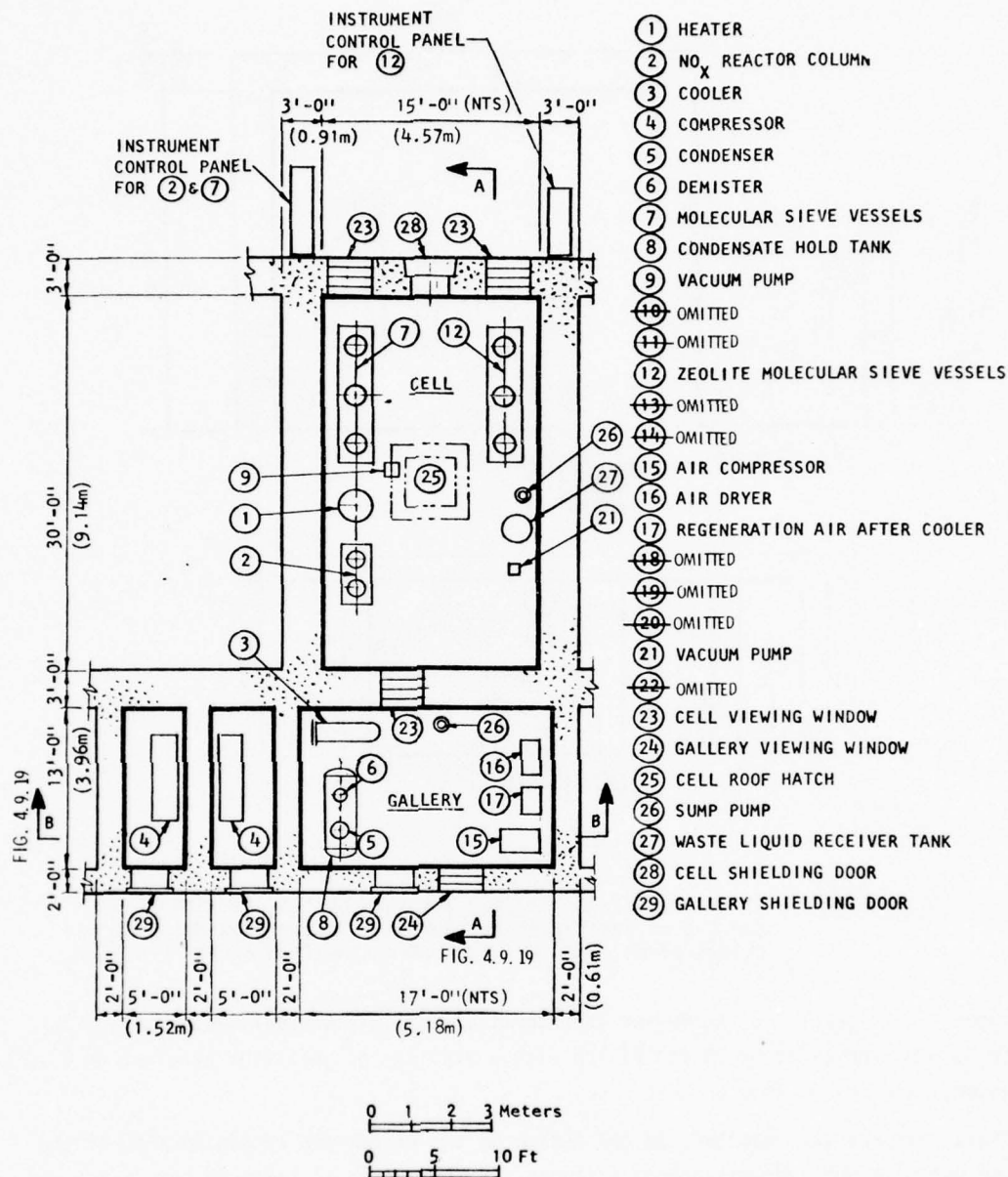


FIGURE 4.9.18. Dissolver Off-gas Krypton Recovery System, General Plan of Facilities for Removing Carbon Dioxide, Oxides of Nitrogen and Water from the Feed Stream

In addition to the krypton cryogenic system equipment, all of the equipment listed in Tables 4.9.17 and 4.9.18 for NO_x and water removal in the carbon-14 recovery facility, as well as the CO₂ molecular sieves, are required for this facility. Other major equipment items required for the krypton recovery system are described below.

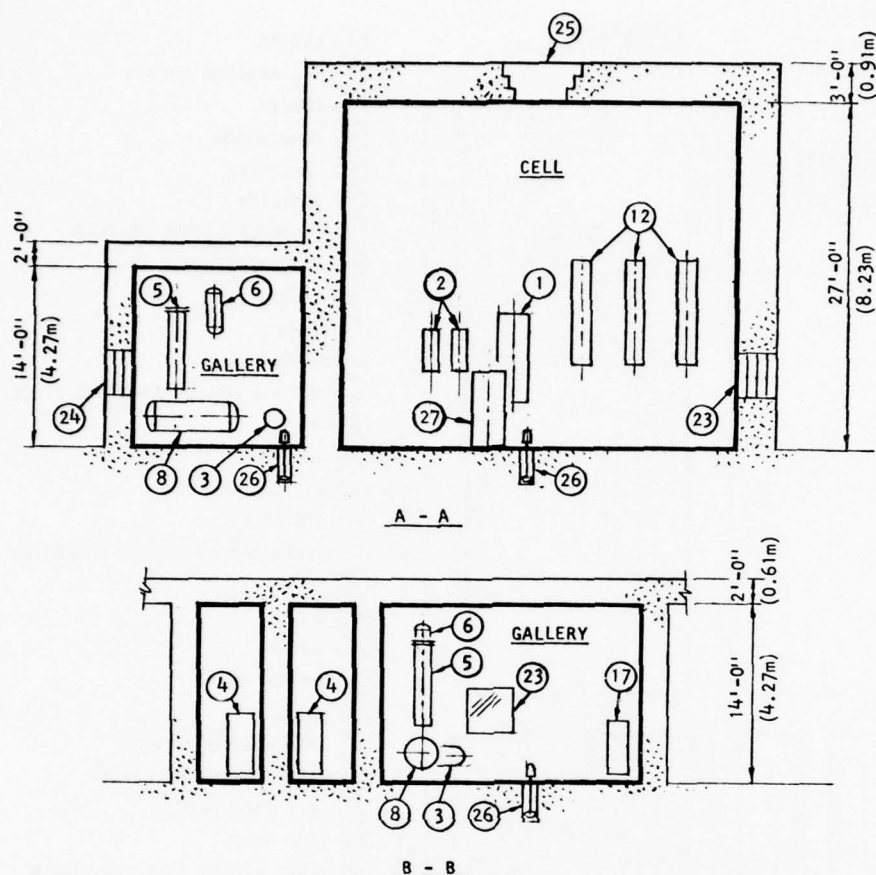


FIGURE 4.9.19. Dissolver Off-gas Krypton Recovery System, Sections A-A and B-B of Facilities for Removing Carbon Dioxide, Oxides of Nitrogen and Water from the Feed Stream

Oxygen Recombiner. The recombinder is a vertical, stainless steel vessel ~ 0.9 m in diameter by 3 m high (3 ft by 10 ft) filled with a platinum or palladium catalyst on a suitable support material to form a packed bed.

Safety features are important in the design of the recombinder system because of the explosion potential of hydrogen-oxygen mixtures. Extreme care is taken in the design and operating features to assure that the 3% hydrogen concentration limit is never exceeded. Hydrogen concentration of feed to the converter is maintained below 3 vol% by recycle of exit gas. A water-cooled shell-and-tube heat exchanger controls the recycle gas temperature, thereby controlling the bed temperature.

Duplicate equipment is provided throughout the recombinder step. Each packed vessel is provided with an explosion disc and relief piping to the outside of the building. Each vessel is enclosed in a three-sided concrete barrier with the fourth side enclosed by a break-away explosion panel directed toward a restricted area outside the building (Figure 4.9.17).

Hydrogen Generator. The amount of hydrogen required for the oxygen recombiner--about $1 \text{ m}^3/\text{min}$ --could be supplied in a number of ways, but a simple electrolytic cell appears most practical when compared to ammonia decomposition or outside purchase. The hydrogen generator produces 9 kg of H_2 per hour by electrolysis of water. The hydrogen produced is at atmospheric pressure and is directed to an interim storage gas holder with a capacity of approximately 1.4 m^3 . By-product oxygen produced is vented to the atmosphere via a separate stack.

Recycle Gas Cooler. The two recycle gas coolers that control the temperature in the recombiner are conventional shell-and-tube heat exchangers made of 347 stainless steel, each approximately 0.4 m in diameter, 2.4 m long, with about a 19-m^2 area, and requiring $0.08 \text{ m}^3/\text{hr}$ of cooling water. U-shaped tubes in vertical orientation are preferred, with water on the tube side and hot gas on the shell side.

Primary Process Gas Condenser. This condenser is of the same design as the recycle gas cooler but with about half the heat transfer surface. The condenser, in horizontal orientation, is approximately 0.3 m in diameter, 2.4 m long, and requires $0.04 \text{ m}^3/\text{hr}$ of cooling water.

Secondary Refrigerated Condenser. This condenser is of conventional stainless shell-and-tube design, with provision for bypassing in the event of mechanical failure. A standard, 2-ton refrigeration unit supplies necessary cooling.

Compressors. Two compressors are required (one spare) to compress the off-gas to 2.4 atm, the cryogenic system operating pressure. As vital pieces of equipment, the compressors must be of high quality. Water-sealed compressors made of 347 stainless steel are specified; they must be capable of delivering $3.4 \text{ m}^3/\text{hr}$ of process off-gas at 2°C and 3.4 atm, and have a negative pressure of 1 atm. These compressors are similar to the caustic solution-sealed compressors in service at the ICPP rare gas recovery facility.

Separator-Demister. The use of liquid seal compressors has the disadvantage of reintroducing water to process gas, which enters the compressors at a dew point of approximately 2°C . The amount of water evaporated is negligible, but free water in the form of droplets and mist must be separated from the gas leaving the compressors. This separation is accomplished in a catch tank 30 cm (1 ft) in diameter by 122 cm (4 ft) high. The tank is constructed of 347 stainless steel; a 347-stainless-steel wire mesh pad 15 cm (6 in) thick is provided at the top of the catch tank.

Process Gas Dryer. A multibed (three beds) silica gel dryer, made of 347 stainless steel and with a design operating pressure of 4.4 atm, is used for process gas drying service. Each bed has sufficient capacity to remove water from $3.4 \text{ m}^3/\text{min}$ ($120 \text{ ft}^3/\text{min}$) of gas at a rate of 1 kg/hr (2.4 lb/hr) for at least eight hours before regeneration is required. The dryer system is equipped with timers and automatic valves to switch from drying to regenerating cycles. Off-gas is valved to the plant stack during regeneration. Dryers are equipped with self-contained heaters, also automatically actuated. A moisture monitor installed in the dried gas line alarms when gas dew point rises to -29°C . The dryer load is 0.8 kg/hr of water while drying process gas at a rate of $2.3 \text{ m}^3/\text{min}$.

Cold Box. All equipment, piping, and accessories required to conduct the cryogenic operations are located in a heavily insulated and shielded, self-contained structure called a cold box. This cold box has inside dimensions of approximately 1.2 x 1.2 x 3.7 m (4 x 4 x 12 ft) with a volume of 5.3 m³ (190 ft³). Internal temperature is -170°C during operations. The cold box shell structure is leak-tight, with a controlled and monitored vent to provide containment and control for process or piping leaks.

Precooler. Process feed gas to the cryogenic system is precooled by cold waste gas exiting the primary absorption-stripping column. Present ICPP design accomplishes this with regenerative exchangers, which require periodic recycle operations because of direct mixing of feed and exit gases. Surface heat exchangers are used in this design to eliminate mixing of the two gas streams. (Shell-and-tube heat exchangers are specified here, but other types of surface exchangers are used in the cryogenic industry and may have advantages.) The exchangers remove approximately 7.3 kWh of heat per hour. The design provides electric heaters at the inlet for warming and thawing one exchanger while the second is in service.

Primary Adsorption-Stripping Column. The primary column is approximately 1.5 m (5 ft) high and about 18 cm (7 in.) in diameter above the feed gas introduction point, and about 11 cm (4 in.) in diameter below. Each section is equipped with approximately 10 sieve trays. A reflux condenser that uses purchased LN₂ for cooling is provided at the top of the primary column. The reflux condenser is required to evaporate an estimated 53 kg of N₂ per hour at slightly above atmospheric pressure and at a boiling temperature of -194°C. Condensing pressure of gas on the column side is 2.7 atm psig; the condensing temperature is -186°C, creating a ΔT of 8°C. These conditions require an estimated 0.5 m² of surface for the reflux condenser. Liquid outflow from the bottom of the column is into a reboiler pot with a capacity of 10 L (2.6 gal) and equipped with external heating elements. All equipment in the reboiler, column, condenser system is copper with silver-soldered connections.

Argon-Nitrogen Stripping Column. The argon-nitrogen stripping column is approximately 7.5 cm (3 in.) in diameter and 1.5 m (5 ft) high. A reflux condenser at the top is cooled by commercial LN₂ and an electrically heated reboiler is provided at the bottom. The reboiler, column, and reflux condenser are all constructed of copper with silver-soldered connections.

Krypton-Xenon Separation Column. The krypton-xenon separation column is approximately 2.5 cm (1 in.) in diameter and 1 m (3.3 ft) high. An electrically heated reboiler is provided at the bottom. Construction is all of copper with silver-soldered connections.

Krypton Receivers. Two 6-L krypton receivers are required. Each one holds approximately four days' production of liquid krypton at 170 atm and at -185°C. The jacketed receivers are cooled with gaseous nitrogen from the argon-nitrogen stripping column reflux condenser and/or the primary column reflux condenser.

Cylinder Filling Station. The gas cylinders are filled outside of the process cold box but within a cell filling station (see Figures 4.9.16 and 4.9.17). The filling station cell is equipped with remote manipulators and a cylinder passthrough port for transfer into an intraplant-transfer shielded container, in which they are removed to the krypton storage facility nearby.

Shielding and Remote Handling Equipment. Although krypton-85 is primarily a beta emitter, it does have a small component of gamma radiation (0.41% of 0.514 MeV). In addition, when large quantities of beta radiation are concentrated in a container, penetrating radiation called bremsstrahlung is generated within the container walls as a secondary effect of absorbing the beta radiation. Thus, substantial shielding may be required.

The process gas to be treated has an activity of 11.4 Ci/m^3 before krypton-85 is concentrated in the cryogenic section of the plant. Equipment used to handle this concentration can be adequately shielded by concrete walls 15 cm (6 in.) thick; limited personnel access to this equipment is required. The activity in the system increases as the process streams are enriched in krypton. The liquified final product has an activity of $\sim 19 \text{ Ci/g}$. One day's production, if stored in a receiver, represents a source of about 50,000 Ci. Two days' production are required to fill one 42.5 l cylinder at 35 atm. Stored as liquid, this represents a source of nearly 104,000 Ci, requiring its own shielding (approximately 5 cm of lead) inside the cold box shield.

The overall cold box krypton inventory, exclusive of the above-mentioned product inventory, is estimated to be 50,000 to 75,000 Ci, located almost entirely in the column reboilers and final product column. Shielding for these sources requires approximately 8 cm lead or its equivalent.

4.9.3.5 Operating and Maintenance Requirements for the Dissolver Off-gas Krypton Recovery System

The reference facility operates as part of the FRP 24 hr a day, 7 days a week, for 300 days of the year. Normal activities include monitoring of the NO_x , H_2O , CO_2 , and krypton removal systems and normal maintenance and replacement.

All normal process operations are handled remotely in the hot cell. The compressors and pump gallery are normally unoccupied; personnel enter only to install or remove equipment. Entry of personnel into the cell or gallery is rigorously controlled to minimize exposure to radiation and contamination hazards. Where infrequent operations, instrument readings, and some maintenance activities are needed, personnel may be exposed to higher dose rates. In such cases the dose is controlled and limited to less than 1 mrem/hr.

Staffing. Estimated staffing requirements for the facility are shown in Table 4.9.32.

TABLE 4.9.32. Dissolver Off-gas Krypton Recovery System Staffing Requirements

<u>Job Description</u>	<u>Personnel Required, man-yr/yr</u>
Operators	5
Radiation monitors	1
Maintenance craftsmen	2

Supplies and Utilities. Table 4.9.33 shows the supplies used in the dissolver off-gas krypton recovery system. Utility requirements are estimated in Table 4.9.34.

TABLE 4.9.33. Dissolver Off-gas Krypton Recovery System Supply Requirements

Description	Use	Annual Requirement
NH ₃	NO _x removal	21,640 kg
Zeolite	CO ₂ removal	0.8 m ³
Zeolite	NO _x removal	0.6 m ³
Zeolite	H ₂ O removal	0.75 m ³
LN ₂	Cold trap	4.0 x 10 ⁵ kg
H ₂	O ₂ removal	6.6 x 10 ⁴ kg
Noble metal catalyst	O ₂ recombination	Unknown
Gas cylinders and caps	Krypton storage	145

TABLE 4.9.34. Dissolver Off-gas Krypton Recovery System Utility Requirements

Utility	Use Rate	Annual Requirement
Electricity	175 kW	1 x 10 ⁶ kWh
Water consumed	6 x 10 ² kg/hr	4 x 10 ⁶ kg

Hazardous Materials. The operations of the krypton recovery facility involve several potentially hazardous materials.

Hydrogen. The conceptual process for removing oxygen from the dissolver off-gas is to react it with hydrogen in a recombiner using a noble catalyst. Hydrogen for the reactor is generated electrolytically (other methods such as ammonia decomposition could be used) and is mixed with incoming process gas and a recycle stream before entering the catalytic reactor. The mixture is maintained at a hydrogen concentration well below its lower explosive limit. With gross malfunction, either the hydrogen generation equipment or the recombiner could contain gas mixtures within the hydrogen-oxygen explosive range.

Design instrumentation and control schemes minimize the probability of formation of an explosive mixture. In addition, the equipment is installed in such a manner that, if the improbable explosive mixture were formed and an explosion resulted, personnel and the remainder of the plant would be protected. To this end, the design concept places both recombiners and the hydrogen generator within three-sided, reinforced concrete barriers. The fourth side is a break-away building wall with a restricted area outside.

Oxides of Nitrogen. Solid oxides of nitrogen in the presence of oxygen can explode even at cryogenic temperatures. Most of the oxides of nitrogen that are evolved in dissolver off-gas are removed in gas processing steps prior to oxygen removal. Nitrous oxide (N₂O) in the gas entering the recombiners is converted to N₂ and H₂O so that with normal operation only trace quantities of NO_x and N₂O are in the gas entering the cryogenic system. A well-designed and properly-operated catalytic recombiner can be expected to reduce free oxygen to fractions of a part per million in exit gas, thus reducing to a very low level the probability of an explosive nitrogen oxide-oxygen reaction.

Ozone. With the very small amounts of oxygen entering the cryogenic system, radiolytic formation of ozone and the attendant possible explosion hazard are not credible.

Oxygen. By-product oxygen produced by the electrolytic hydrogen generator presents a potential hazard. However, appropriate venting and standard safety practices for design and operation reduce the hazard to negligible levels.

4.9.3.6 Secondary Radioactive Waste for the Dissolver Off-gas Krypton Recovery System

Estimates of secondary radioactive wastes associated with the reference facility are shown in Table 4.9.35.

TABLE 4.9.35. Dissolver Off-gas Krypton Recovery Facility System Radioactive Wastes

Description	Volume, m ³ /year	Radioactivity Factor ^(a)
Combustible and compactable waste	50	1×10^{-5}

a. Fraction of input activity (Table 4.9.14, excluding volatiles) in secondary wastes.

4.9.3.7 Emissions from the Dissolver Off-gas Krypton Recovery System

Facility emissions are characterized in Table 4.9.36.

TABLE 4.9.36. Dissolver Off-gas Krypton Recovery System Emissions

Emission	Description	Annual Quantity	Radioactivity Release Factor to Atmosphere ^(a)
Gaseous	Dissolver Off-gas	N ₂ 9.6×10^5 m ³	³ H 1.0 ^(b)
		O ₂ 5.0×10^5 m ³	¹⁴ C 1.0
		H ₂ 8.0×10^2 kg	⁸⁵ Kr 0.1
			¹²⁹ I 1.0
			¹⁰⁶ Ru-Rh 0.9 ^(c)
	Minor accident integrated annual release		All others 1×10^{-4}
			Included in operational release
Cooling tower water	• evaporated, T=38°C	3.5×10^6 kg	
	• drift, T=38°C	1.7×10^4 kg	
	• blowdown, T=27°C	6.0×10^5 kg	
Other	Heat	2.4×10^3 MW-hr	
		$(8.0 \times 10^9$ Btu)	

a. Fraction of input activity (Table 4.9.14) released to atmosphere. Includes DF from main plant APS where applicable. Released over 300 days/yr. Peak release rates are approximately 10 times larger than the average rate.

b. Removed from dissolver off-gas but ultimately released via FRP excess water vaporizer.

c. Assumes that the volatile ruthenium is not converted to particulate ruthenium by the time it reaches the APS.

4.9.3.8 Decommissioning Considerations for the Dissolver Off-gas Krypton Recovery System

The facility housing the dissolver off-gas krypton recovery system is designed to be functional for the life of the FRP. At the end of the reference facility's operating life, the portion of the facility devoted to removing NO_x , H_2O , and CO_2 is expected to be relatively free of external contamination. The ability to remove the solid sorbents aids in decontamination. The krypton portion of the facility will have very low contamination levels. Ease of retirement and removal is an important consideration in selecting all materials and equipment for the facility.

4.9.3.9 Postulated Accidents for the Dissolver Off-gas Krypton Recovery System

Scenarios of postulated minor and moderate accidents for the krypton recovery system are listed in Tables 4.9.37 and 4.9.38. No accidents that could be classified as severe could be realistically postulated for this technology. A moderate accident was identified, with krypton-85 venting to the FRP stack for 30 days owing to a cryogenic equipment failure (Accident 4.9.11). It is assumed that the FRP would be allowed to continue to operate, with venting of krypton for this period. A failure in the CO_2 removal system would also require krypton venting.

TABLE 4.9.37. Dissolver Off-gas Krypton Recovery Facility Minor Accidents

Accident No. and Description	Sequence of Events	Safety System	Release
4.9.9 - Plugged lines.	1. H_2O condenser or demister plugged. 2. See Table 4.9.25, Accident 4.9.6, numbers 2 through 5.	1. See Accident 4.9.6.	Minor leakage included in operational releases.
4.9.10 - Freezing	1. Line plugs because of accumulation of ice and nitrogen oxides. 2. Loss of gas flow is identified by instrumentation. 3. Dual system is switched into service. 4. The plugged system is warmed and purged to remove the ice plug. 5. The exchanger is returned to service.	1. Air flow monitoring system provides continuous information. 2. The cryogenic system has redundant units installed in parallel. 3. The gas flows are capable of being rerouted to the second unit while the FRP is in service.	Minor leakage included in operational releases.

4.9.3.10 Facility Costs for the Dissolver Off-gas Krypton Recovery System

Estimates have been made, in mid-1976 dollars, of incremental capital, operating, and levelized unit costs. A complete description of the cost estimate bases, assumptions and definitions is given in Section 3.8.

Capital Costs. The capital cost estimates for the krypton recovery system are shown in Table 4.9.39. The incremental capital cost for this system is determined as an addition to the iodine recovery system (Section 4.9.1). The estimate covers all capital costs specifically resulting from the inclusion of the reference facilities as an integral part of the reference

TABLE 4.9.38. Dissolver Off-gas Krypton Recovery System Moderate Accidents

Accident No. and Description	Sequence of Events	Safety System	Release
4.9.11 - Process shutdown, with ^{85}Kr venting.	1. Recovery system shut down because of equipment failure. Radiation and airflow monitoring systems record venting of Kr directly to APS and and FRP main stack.	1. Redundant equipment installed. Radiation and airflow monitoring systems provide continuous information.	If the DOG is vented directly to the stack after treatment, approximately 5.6×10^4 Ci of ^{85}Kr would be released per day. Current practice allows complete Kr release. Short-term releases in future reprocessing plants would have lesser consequences
	2. Dissolver and main FRP continues to process for 30 days	2. If repairs are not completed within 30 days the FRP is shut down.	
	3. Offsite Kr concentrations monitored to assure adequate dispersion.	3. Offsite monitoring system installed.	
	4. Equipment repaired and returned to service.		
4.9.12 - Oxygen recombiner explosion.	1. Gases in recombiner reach detonation limit (4 vol% H_2) owing to failure of exit gas recycle or poisoned bed.	1. Instrumentation and alarms monitor H_2 levels. Exit gas piping designed to assure adequate recycle.	53 Ci ^{85}Kr released at ground level through the building breach.
	2. Gases ignite.	2. No ignition sources present.	
	3. Rupture disk vents to relief piping. Choked flow develops.	3. Rupture disk sized for deflagrations and minor overpressures.	
	4. Vessel ruptures.	4. Explosion barriers and break-away building panels provided to mitigate explosion energy.	
	5. Off-gas stream routed to redundant system.	5. Redundant recombiner installed in parallel.	
	6. Failed recombiner replaced.		

FRP, including the costs of incremental additions to heating, ventilation, and air conditioning (HVAC) and utilities, as well as bulk materials for piping, electrical and instrument tie-ins with the FRP. However, general FRP costs for such services as laboratories, personnel facilities, health physics support, warehousing, shops, and administration buildings have not been allocated to the krypton recovery system.

The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation, with the exception of working capital.

Operating Costs. Table 4.9.40 lists the operating cost components for the DOG krypton recovery system. Direct labor costs are based on the manpower requirements in Table 4.9.32. Process materials and utilities costs are derived from requirements shown in Tables 4.9.33 and 4.9.34. The gas storage cylinders are estimated to cost \$3,000 each and are the largest cost item in the operating cost, accounting for about 40% of the total. Annual maintenance materials costs are estimated at 3% of the initial major equipment cost. Overhead and miscellaneous costs were calculated as described in Section 3.8.

TABLE 4.9.39. Capital Cost Estimate for the Dissolver Off-gas Krypton Recovery System

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		20	5,400	200	5,600
Buildings and structures		80	800	900	1,700
Bulk materials		140	2,600	1,700	4,300
Site improvements		10	--	100	100
Subtotal of direct site construction costs		250	8,800	2,900	11,700
Indirect site construction costs	60	50	1,000	1,400	2,400
Total field cost	60	300	9,800	4,300	14,100
Architect-engineering services					2,800
Subtotal					16,900
Owner's cost					5,100
Total facility cost					22,000
Estimate accuracy range					±30%

TABLE 4.9.40. Operating Cost Estimate for the Dissolver Off-gas Krypton Recovery System

Cost Element	Annual Costs, \$1000s
Direct labor	120
Process materials	520
Utilities	25
Maintenance materials	160
Overhead	225
Miscellaneous	30
Total	1,080 +50% -25%

Levelized Unit Costs. The total levelized unit cost, including levelized capital and operating components, is presented in Table 4.9.41. The cost calculation assumes private ownership and a 15-year economic life.

TABLE 4.9.41. Levelized Unit Cost Estimate for the Dissolver Off-gas Krypton Recovery System

Cost Element	Unit Cost, \$/kg HM
Levelized capital charge	2.80
Levelized operating charge	0.60
Levelized total unit cost	3.40 ±35%

4.9.57

4.9.3.11 Construction Requirements for the Dissolver Off-gas Krypton Recovery System

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating this impact. The values given below describe incremental costs for krypton recovery only when added to the iodine recovery system (Section 4.9.1).

Project Schedule and Construction Manpower. The schedule for engineering, procurement and construction of the krypton recovery facility and systems is an integral factor in the overall schedule for the FRP. The field labor force estimated for the construction of the krypton recovery facility is tabulated below:

	Man-hours, 1000s
Manual field labor	300
Nonmanual field labor	<u>60</u>
Total field labor	360

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials and services provided at the site of the FRP, while offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is as follows:

	Costs, \$1000s
Onsite	5,000
Offsite	<u>17,000</u>
Total	22,000

Site Requirements. No additional site requirements beyond those for the FRP are identifiable for the krypton recovery system. Commitments of land for the reference system are included with those of the FRP.

Water. Water used during the construction period is estimated at $4,200 \text{ m}^3$ (1.1×10^6 gal).

Construction Materials. Materials committed to the reference facility construction are:

Concrete	$1,450 \text{ m}^3$	(1,900 yd^3)
Steel	425 MT	(470 tons)
Copper	3.6 MT	(4 tons)
Zinc	negligible	
Aluminum	negligible	
Lumber	50 m^3	(20 MBFM)

Energy. Resources of energy expected to be used during construction are:

Propane	42 m ³	(11,000 gal)
Diesel	416 m ³	(110,000 gal)
Gasoline	265 m ³	(70,000 gal)
Electricity		
Peak demand	300 kW	
Total consumption	200,000 kWh	

Transportation Requirements. No transportation requirements for the krypton recovery system have been identified beyond those for the FRP.

4.9.3.12 Effects of Fuel Cycle Options

The reference process for the krypton recovery system assumes reprocessing of LWR fuel and recycling the retrieved uranium and plutonium. The following alternative fuel cycle modes have also been assessed insofar as they relate to this system.

No Recycle. Eliminating the fuel reprocessing operation eliminates the generation of dissolver and processing off-gases. Accordingly, no krypton recovery system is required.

Uranium Recycle Only, with Plutonium to a Repository. This alternative is expected to generate about the same amount of dissolver and processing off-gas in the uranium and plutonium recycle case.

Uranium Recycle Only, with Plutonium to HLW. This alternative would generate about the same quantity of dissolver and processing off-gas as in the uranium and plutonium recycle case.

4.9.4 Combined Dissolver Off-gas Treatment System

A dissolver off-gas (DOG) treatment system is described here that combines recovery of iodine, carbon-14, and krypton in an integrated system. This system comprises silica gel and zeolite beds to remove ruthenium and iodine, a catalytic reactor to remove NO_x, a series of zeolite beds to remove H₂O and CO₂, and a cryogenic system to recover a mixture of Xe, Kr, Ar, and N₂. The liquified gas mixture is then fractionated to obtain a final product containing about 80% krypton. The CO₂ captured on the molecular sieve (zeolite) is desorbed and disposed of as solid CaCO₃. The iodine and ruthenium adsorber cartridges are removed from service and disposed of as waste when their capacity has been reached. The krypton is placed in high pressure cylinders and sent to a storage facility adjacent to the reference fuel reprocessing plant.

4.9.4.1 Process Alternatives for Combined Dissolver Off-gas Treatment

Process alternatives for the subsystems that compose the combined off-gas recovery system have been described in Sections 4.9.1.1, 4.9.2.1 and 4.9.3.1. Previous reprocessing facilities have removed iodine and ruthenium by various methods. Krypton and carbon have been allowed to be released from the FRP stack.

4.9.4.2 Design Basis for the Combined Dissolver Off-gas Treatment System

The following assumptions were made in the design of the reference system:

- The combined DOG treatment system operates 300 days per year and treats off-gas from the 2000-MWTH/yr reference FRP.
- The FRP fuel shear off-gas is combined with the DOG.
- The design volumetric flow is approximately $2.8 \text{ m}^3/\text{min}$ ($100 \text{ ft}^3/\text{min}$).
- The system is incorporated as an integral part of the FRP.
- The combined system is designed to achieve a DF of 10^5 for particulate ruthenium and other particles, 10^4 for volatile ruthenium, 10^3 for iodine, 10^2 for carbon-14, and 10^1 for krypton.

4.9.4.3 Combined Dissolver Off-gas Treatment Process

The reference dissolver off-gas composition is listed in Table 4.9.1. In the iodine recovery facility, this off-gas is passed through a water scrubber for NO_x and particle removal, a heater to raise the gas temperature above the dew point, a ruthenium absorber, a glass fiber filter (HEPA filter) for additional particle removal, a second heater to increase the temperature of the gas to 150°C , and through an iodine adsorber for recovery of volatile iodine. The DOG leaving the iodine recovery subsystem (see Section 4.9.1) contains oxides of nitrogen, water vapor, including tritium from the dissolver, and rare gases including krypton.

The gas from the iodine recovery facility then passes through an electric heater that raises the gas temperature to about 350°C , the temperature required for operation of the second NO_x removal system. The gas exits the heater and flows through a packed bed of synthetic mordenite. Near stoichiometric amounts of ammonia are added to the gas stream just prior to entrance of the zeolite bed that catalyzes the reaction of NO_x with ammonia to produce nitrogen and water.

Next, the gas flows through two zeolite molecular sieve beds connected in series for water removal, followed by two zeolite beds connected in series for CO_2 removal. (See Section 4.9.2 for details concerning the carbon-14 removal subsystem). Water removal sieves are regenerated by releasing the pressure on the bed. Carbon dioxide removal sieves are regenerated by a similar process, and the resulting CO_2 gas flows to the CO_2 fixation tower, where it bubbles through a saturated solution of Ca(OH)_2 to form the carbonate. The calcium carbonate is separated using a vacuum drum filter, then dried and sent to a drumming station for removal to final isolation. The rare gases found in the DOG are not captured by either the iodine or carbon recovery subsystems but are passed to the krypton recovery subsystem (see Section 4.9.3).

The inflow stream to the krypton recovery subsystem consists primarily of air with very small amounts of NO_x and water. The oxygen is removed as water by reacting it with hydrogen in a catalytic recombiner. The hydrogen is supplied by an electrolytic generator. The gas is refrigerated to condense out the water and passed through silica gel dryers for final water removal. The gas then enters the cryogenic absorption, stripping, distillation, and recovery subsystems. The krypton gas is placed in cylinders at 35 atm pressure and sent to the krypton storage facility for extended storage during decay of the krypton-85 (see Section 5.6).

Figure 4.9.20 is a process flow diagram for the combined DOG treatment system. The subsystem process flowsheets are shown in Figures 4.9.1, 4.9.8, and 4.9.15; the chemical material balances are shown in Tables 4.9.2, 4.9.15 and 4.9.30. Process details are described in the cited subsections. Solid wastes resulting from the combined DOG treatment system are summarized in Table 4.9.42.

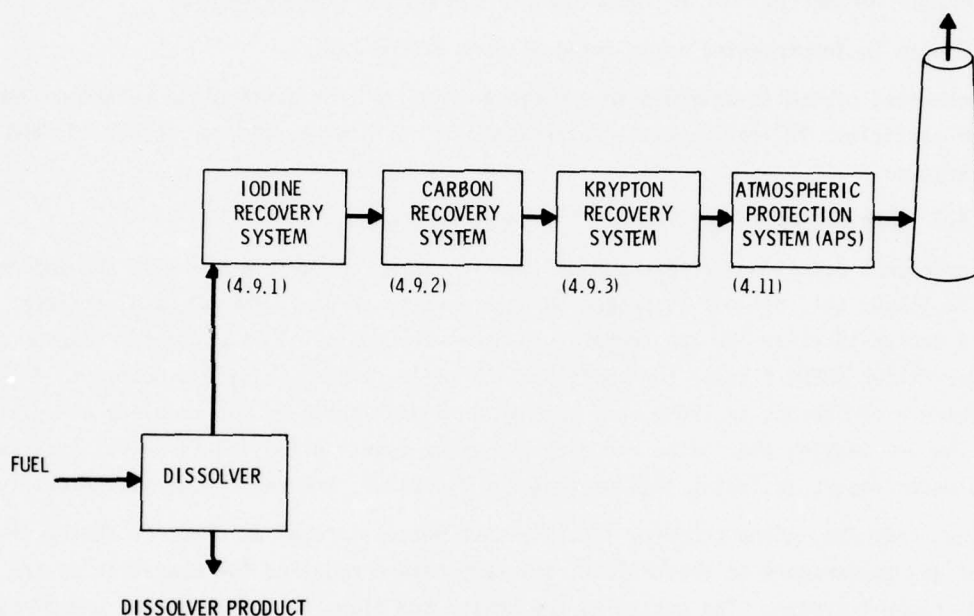


FIGURE 4.9.20. Process Flow Diagram for the Combined Dissolver Off-gas Treatment System

TABLE 4.9.42. Description of Packaged Waste from Combined DOG Treatment System

Waste type and contained surface dose rate class, R/hr	Volume, m ³ /hr	Density, kg/m ³	Containers/yr		Radioactivity Factor ^(a)
			55-gal drums	gas cylinders	
Silver-zeolite <0.2 R/hr	7.6	700	36		¹²⁹ I = 1.0 Other = negligible
CaCO ₃ <0.2 R/hr	2	1,300	10		¹⁴ C = 1.0 Other = negligible
Silica gel adsorbant >10 R/hr	0.5	700	2.4		¹⁰⁶ Ru-Rh = 0.05 Other = negligible
Krypton gas cylinders >10 R/hr	6.2			145	⁸⁵ Kr = 0.9 Other = negligible

a. Fraction of input activity from Table 4.9.1.

4.9.4.4 Facility Description for the Combined Dissolver Off-gas Treatment System

The dissolver off-gas iodine, carbon-14 and krypton recovery subsystems are designed to be an integral part of the reference fuel reprocessing plant (FRP). The combined treatment system has sufficient capacity to handle the total DOG stream from the reference FRP. The approximate location of the facilities for the treatment system is shown on the plot plan for the FRP, Figure 4.9.2. Plan and section views for the iodine carbon and krypton removal subsystems are shown in Figures 4.9.3, 4.9.4, 4.9.13, 4.9.14, 4.9.16, and 4.9.17.

The combined facility includes the cells and galleries described in Sections 4.9.1, 4.9.2, and 4.9.3, with the exception of the H_2O , NO_x and CO_2 removal system discussed in Section 4.9.3. Service and support facilities associated with the combined system include:

- main control room area, including space on the main control panel
- ventilation system for the process cells, including space for equipment and ducts
- heating, ventilation and air conditioning of associated service and support area
- cell handling and maintenance areas, including the bridge crane and the truck loading and unloading area
- equipment maintenance areas.

All process equipment is enclosed within Category I cells and galleries constructed of reinforced concrete. Cells are provided with floor pans, sumps and protective coatings to facilitate decontamination and to cope with possible spills. The facilities shown are enclosed within the outer walls of the Category I FRP structure and share common use of FRP services, utilities, laboratories, health physics support, operating personnel change areas, maintenance areas, warehousing, shops and offices.

4.9.4.5 Operating and Maintenance Requirements for the Combined Dissolver Off-gas Treatment Facility

The system operates as part of the FRP 24 hr a day, 7 days a week, 300 days a year. The carbon fixation portion of the facility operates 8 hours per day. Normal activities include monitoring of the iodine, ruthenium, NO_x , H_2O , CO_2 and krypton removal subsystems, and normal maintenance and replacement.

All normal process operations are handled remotely in the hot cells, and radiation dose rates are limited to less than 1 mrem/hr. Where infrequent operations, instrument readings, and some maintenance activities are required through entry into the valve and pump galleries, personnel may be briefly exposed to higher dose rates. In such cases, exposure is rigorously controlled.

Staffing. Estimated staffing requirements for the facility are shown in Table 4.9.43.

TABLE 4.9.43. Combined Dissolver Off-gas Treatment System Staffing Requirements

Job Description	Personnel Required, man-yr/yr
Operators	6.5
Radiation monitors	1.75
Maintenance craftsmen	3.25

Supplies and Utilities. Table 4.9.44 shows the supplies used in the combined dissolver off-gas treatment system. Estimates of utility requirements are shown in Table 4.9.45.

TABLE 4.9.44. Combined Dissolver Off-gas Treatment System Supply Requirements

Description	Use	Annual Requirement
Silica gel	Ru recovery	0.5 m ³
Silver-zeolite	I ₂ recovery	6.6 m ³
CaO	CO ₂ fixation	1,450 kg
NH ₃	NO _x removal	21,640 kg
Zeolite	CO ₂ removal	0.8 m ³
Zeolite	H ₂ O removal	0.75 m ³
Zeolite	NO _x removal	0.6 m ³
LN ₂	Cold trap	4.0 x 10 ⁵ kg
H ₂	O ₂ removal	6.6 x 10 ⁴ kg
Noble metal catalyst	O ₂ recombination	Unknown
Gas cylinders and caps	Kr storage	145

TABLE 4.9.45. Combined Dissolver Off-gas Treatment System Utility Requirements

Utility	Use Rate	Annual Requirement
Electricity	200 kW	1.3 x 10 ⁶ kWh
Water consumed	0.6 m ³ /hr	4000 m ³
Steam	42 kg/hr	3 x 10 ⁵ kg

4.9.4.6 Secondary Radioactive Wastes for the Combined Dissolver Off-gas Treatment System

Estimates of secondary radioactive wastes associated with the reference facility are shown in Table 4.9.46.

TABLE 4.9.46. Combined Dissolver Off-gas Treatment System
Secondary Radioactive Wastes

Description	Volume, m ³ /year	Radioactivity Factor ^(a)
Combustible and compactable waste	80	1×10^{-5}

a. Fraction of input activity (Table 4.9.1, excluding volatiles) in secondary wastes.

4.9.4.7 Emissions from the Combined Dissolver Off-gas Treatment System

Facility emissions are characterized in Table 4.9.47.

TABLE 4.9.47. Combined Dissolver Off-gas Treatment System Facility Emissions

Emission	Description	Annual Quantity	Radioactivity Release Factor to Atmosphere ^(a)
Gaseous	Dissolver Off-gas	N ₂ 9.6×10^5 m ³	³ H 1.0 ^(b)
		O ₂ 5.0×10^5 m ³	¹⁴ C 1×10^{-2}
		H ₂ 8.0×10^2 kg	⁸⁵ Kr 0.1
			¹²⁹ I 1×10^{-3}
			¹⁰⁶ Ru-Rh $5 \times 10^{-5(c)}$
			All others 1×10^{-9}
	Minor accident integrated annual release		Included in operational release
Cooling tower water	• evaporated, T=38°C	3.5×10^6 kg	
	• drift, T=38°C	1.7×10^6 kg	
	• blowdown, T=27°C	6.0×10^5 kg	
Other	Heat	2.4×10^3 MW-hr	
		$(8 \times 10^9$ Btu)	

a. Fraction of input activity (Table 4.9.1) released to atmosphere. Includes DF from main plant APS where applicable. Released over 300 days/yr. Peak release rate is approximately 10 times the average rate.

b. Removed from dissolver off-gas but ultimately released via FRP excess water vaporizer.

c. Assumes that the volatile ruthenium is not converted to particulate ruthenium by the time it reaches the APS.

4.9.4.8 Decommissioning Considerations for the Combined Dissolver Off-gas Treatment System

The dissolver off-gas recovery subsystems required to capture iodine, ruthenium, carbon dioxide and krypton are designed to be functional for the life of the FRP. At the end of the reference FRP's operating life, the recovery facilities are expected to be relatively free of external contamination. The ability to remove the silica gel, the silver-zeolite, the other zeolites (required for H₂O, NO_x and oxygen removal), and the HEPA filters aid in decontamination.

4.9.4.9 Postulated Accidents for the Combined Dissolver Off-gas Treatment System

Scenarios of postulated accidents for the combined dissolver off-gas treatment system are listed in Tables 4.9.9, 4.9.10, 4.9.25, 4.9.26, 4.9.37, 4.9.38, and 4.9.48. The loss of flow in either a ruthenium, or iodine bed (Table 4.9.9) is considered a minor accident with no release to the atmosphere. The loss of flow in the CO₂ fixation tower (Table 4.9.25) would not shut down main FRP process. The recovery of CO₂ on the zeolite system would continue for 16 hours without release to the atmosphere. A torn HEPA filter (Table 4.9.9) can be isolated from the system for replacement; during this replacement radioactive releases would not exceed normal operational releases through the FRP stack. Moderate accidents were identified as a spill of the silica gel or zeolite during canister replacement process shutdown with volatile venting for one day, and venting CO₂ and krypton-85 to the stack for 30 days. No accidents that could be classified as severe accidents could be realistically postulated for this technology.

Accident 4.9.13 illustrates the releases which may occur in the unlikely event of a complete failure of the off-gas treatment system. It is expected that the FRP would continue to operate up to one day to finish processing inventories in the dissolver. Accident 4.9.14 shows releases which may occur if the FRP is allowed to operate with the carbon recovery and krypton recovery system shut down. This may occur if problems develop in the cryogenics or molecular sieves used in these processes. The complete dissolver off-gas system contains many redundant components, and several equipment failures must occur before these releases are initiated.

The source terms from Accidents 4.9.13 and 4.9.14 have been designated as umbrella source terms (see Section 3.7-Basis for Accident Analyses). This means that releases from these accidents involved the largest amounts of activity in their release group from accidents in the waste management system. Source term categories are cross-indexed by accident number in Appendix A of Section 3.

4.9.4.10 Facility Costs for the Combined Dissolver Off-gas Treatment System

Estimates have been made, in mid-1976 dollars, of incremental capital operating and levelized unit costs for the combined DOG treatment system. A complete description of the cost estimate bases, assumptions and definitions is given in Section 3.8.

Capital Costs. The capital cost estimates for the combined DOG treatment system shown in Table 4.9.49 cover all capital costs specifically resulting from the inclusion of the system as an integral part of the primary reference FRP. These costs also include the costs of incremental additions to heating, ventilation, and air conditioning (HVAC) and utilities, as well as bulk materials for piping, electrical and instrument tie-ins with the FRP. However, no general FRP costs for such services as laboratories, personnel facilities, health physics support, warehousing, and shops are allocated to the reference system.

The total capital cost includes all plant related costs incurred from the start of engineering to the initiation of commercial operation.

Operating Costs. The operating cost components for the combined dissolver off-gas treatment system are shown in Table 4.9.50. Direct labor costs are based on the manpower requirements in Table 4.9.43. Process materials and utilities costs are derived from the requirements shown in Tables 4.9.44 and 4.9.45. Maintenance materials costs are estimated at 3% of the initial major equipment cost. Overhead and miscellaneous costs are calculated as described in Section 3.8.

TABLE 4.9.48. Combined Dissolver Off-gas Treatment Facility Moderate Accidents

Accident No. and Description	Sequence of Events	Safety System	Release
4.9.13 - Process shut-down with volatile venting - one day/yr.	<ol style="list-style-type: none"> Both the iodine and ruthenium adsorber systems fail. All volatile isotopes (I_2, Kr, and C) vent to the FRP-APS for one day while the plant shuts down. Radiation and airflow monitor systems detect venting of DOG directly to APS and FRP main stack. Dissolver and main process are shut down. However DOG is shut down only after material in dissolver is processed. FRP continues to process until out of dissolver feed. 	<ol style="list-style-type: none"> Redundant treatment modules available for both I and Ru. Radiation and airflow monitoring systems provide continuous information. Offsite monitoring system is installed. 	<ol style="list-style-type: none"> If the DOG is vented to the stack with a gas flow of $2 \times 10^5 \text{ m}^3/\text{hr}$, the iodine concentration would be $2.6 \times 10^5 \text{ } \mu\text{Ci/day}$; the ^{85}Kr release would be $5.6 \times 10^4 \text{ Ci/day}$; and the ^{14}C release would be 5 Ci/day. Current practice allows complete Kr and C release. An additional DF of 10^4 could be assumed for Ru as it passed through the APS and would be below the controlled area guideline.
4.9.14 - Process shut-down with ^{14}C and ^{85}Kr venting - 30 days.	<ol style="list-style-type: none"> Carbon-14 and krypton-85 systems bypassed for 30 days due to process equipment failure. Dissolver and other volatile recovery systems continue (I, Ru, H_2O and NO_x) to operate. If repairs are not completed within 30 days the FRP is shut down. Equipment repaired and returned to service. 	<ol style="list-style-type: none"> Redundant equipment installed. Radiation and airflow monitoring systems provide continuous information. Offsite monitoring system is installed. 	<ol style="list-style-type: none"> If the carbon-14 and krypton-85 are released to the stack, approximately 150 Ci of ^{14}C and $1.7 \times 10^6 \text{ Ci}$ of ^{85}Kr would be released. Current practice allows complete release of carbon and krypton.

TABLE 4.9.49. Capital Cost Estimate for the Combined Dissolver Off-gas Treatment System

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		20	6,800	300	7,100
Buildings and structures		140	1,600	1,700	3,300
Bulk materials		240	4,100	2,900	7,000
Site improvements		10	--	100	100
Subtotal of direct site construction costs		410	12,500	5,000	17,500
Indirect site construction costs	100	80	1,800	2,400	4,200
Total field cost	100	490	14,300	7,400	21,700
Architect-engineering services					4,300
Subtotal					26,000
Owner's cost					8,000
Total facility cost					34,000
Estimate accuracy range					$\pm 30\%$

TABLE 4.9.50. Operating Cost Estimate for the Combined Dissolver Off-gas Treatment System

Cost Element	Annual Costs, \$1000s
Direct labor	200
Process materials	1,015
Utilities	40
Maintenance materials	225
Overhead	290
Miscellaneous	80
Total	1,850 ^{+50%} _{-25%}

Levelized Unit Costs. Table 4.9.51 lists the total levelized unit cost, including the levelized capital and operating components. The cost calculation assumes private ownership of the facilities and a 15-year economic life.

TABLE 4.9.51. Levelized Unit Cost Estimate for the Combined Dissolver Off-gas Treatment System

Cost Element	Unit Cost, \$/kgHM
Levelized capital charge	4.20
Levelized operating charge	1.00
Levelized total unit cost	5.20 $\pm 40\%$

4.9.4.11 Facility Construction Requirements for the Combined Dissolver Off-gas Treatment System

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information which follows provides a basis for evaluating this impact.

Project Schedules and Construction Manpower. The schedule for engineering, procurement and construction of the combined system is an integral factor in the overall schedule for the FRP. The field labor force estimated for construction of the reference facility is tabulated below:

	Man-hours, 1000s
Manual field labor	490
Nonmanual field labor	100
Total field labor	590

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials, and services provided at the site of the FRP, while offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is as shown below:

4.9.67

	Costs, \$1000s
Onsite	8,000
Offsite	<u>26,000</u>
Total	34,000

Site Requirements. The facilities for the combined DOG treatment system share the same site as the FRP. No additional site requirements beyond those for the FRP are identifiable.

Water. Water used during the construction period is estimated at $6,800 \text{ m}^3$ (1.8×10^6 gal).

Construction Materials. Materials committed to the construction of the combined system are:

Concrete	$2,600 \text{ m}^3$	(3,400 cu yds)
All steel	660 MT	(730 tons)
Copper	6.4 MT	(7 tons)
Zinc	negligible	negligible
Aluminum	negligible	negligible
Lumber	90 m^3	(40 MBFM)

Energy. Energy resources used during construction are:

Propane	64 m^3	(17,000 gal)
Diesel	660 m^3	(174,000 gal)
Gasoline	440 m^3	(116,000 gal)
Electricity		
Peak demand	500 kW	
Total consumption	330,000 kWh	

Transportation Requirements. No transportation requirements for combined DOG treatment system have been identified beyond those for the FRP.

4.9.4.12. Effects of Fuel Cycle Options

The reference process for the complete dissolver off-gas system assumes reprocessing of LWR fuel and recycling the retrieved uranium and plutonium. The following alternative fuel cycle modes have also been assessed insofar as they relate to DOG treatment.

No Recycle. Eliminating the fuel reprocessing operation does away with the generation of dissolver and processing off-gases. Accordingly, no off-gas treatment system is required.

Uranium Recycle Only, with Plutonium to High-Level Waste. This alternative is expected to generate about the same amount of dissolver and processing off-gas as in the uranium and plutonium recycle case.

Uranium Recycle Only, with Plutonium to High-Level Waste. This alternative would generate about the same quantity of dissolver and processing off-gas as in the uranium and plutonium recycle case.

4.9.5 Physical Protection and Safeguards Requirements for Fuel Reprocessing Plant Dissolver Off-Gas Treatment Facilities

The gaseous radionuclides ^{85}Kr , ^{14}C , and ^{129}I are the principal products in the FRP dissolver off-gas treatment facilities. Except for concentrated krypton gas, all of the gases are non-toxic in the amounts found in any step in the treatment facility and too low in concentration to be a health hazard to the public if released on site in an act of sabotage. Neither ^{14}C , packaged as CaCO_3 , nor ^{129}I , packaged as a spent silver zeolite bed, are attractive targets for theft and eventual dispersal or for deliberate dispersal on site as a result of sabotage. Krypton-85 is concentrated in a cryogenic fractionation facility and collected as a gas for storage in gas cylinders. In this concentrated form it could be hazardous in an uncontrolled release. The safeguards and physical protection requirements for storage of these gas cylinders is discussed in Section 5.6.3.

The treatment facilities for dissolver off-gas will be located within the vital areas of an FRP where the physical security requirements for vital areas apply.

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4.10 PROCESS OFF-GAS TREATMENT

4.10 PROCESS OFF-GAS TREATMENT

Process off-gas comprises gases emitted from process vessels, storage tanks, airlift vents, selected fuel storage areas, aqueous concentrators and calciners at fuel cycle facilities. Also included with process off-gas is the secondary off-gas generated by solid waste incinerators and high-level liquid waste concentrators used for processing primary waste. Within each major fuel cycle facility, off-gas from the various processes are, for the most part, combined and treated as a homogeneous stream. Exceptions to this procedure include the off-gas from the fuel reprocessing plant (FRP) dissolver, which requires a separate treatment system (see Section 4.9). The treatment of process off-gas is designed to remove radioactive particles, gases and toxic chemicals from the off-gas before it is released to an atmospheric protection system (see Section 4.11) or to the biosphere.

4.10.1 Process Off-gas Treatment at the Fuel Reprocessing Plant

Off-gases from the fuel storage process vent and from all of the process vessels within the reference FRP except the fuel shear and dissolver, the UF_6 off-gas system, and the excess H_2O vaporizer are treated by the vessel off-gas (VOG) system. This system is designed to remove particles, iodine, and oxides of nitrogen from the off-gas before it is released to the atmospheric protection system (APS) for final filtration and discharged through the main FRP stack.

4.10.1.1 Alternative Vessel Off-gas Treatment Methods

Alternatives for iodine recovery have been described in Section 4.9.1.1 for the FRP dissolver off-gas system; these same alternatives also apply to the VOG system. Alternative particle removal systems have been described in Section 4.8.

The system for removing oxides of nitrogen (NO_x) is identical to the process described in Section 4.9.2.3 selected for the FRP vessel off-gas system. This technology, which is based on catalytic reduction by NH_3 and removes 99.9% of the NO_x in the off-gas stream, is relatively new; it was selected, however, after reviewing and rejecting the following alternatives:⁽¹⁾

- Release without recovery. This alternative was considered unacceptable.
- Aqueous scrubbing technology. With this method, removal efficiencies above 70% are seldom obtained.
- Nonselective, gas-phase reduction. This process was tested by the Atlantic Richfield Hanford Company and by American Cyanamid, who report that about 90% abatement of 1% NO_x in air can be obtained when the off-gas reacts with a reductant such as H_2 , CO, CH_4 or propane.

4.10.1.2 Vessel Off-gas System Design Basis

The design basis VOG composition is shown in Table 4.10.1. The following assumptions were made in the design of the reference facility:

- The vessel off-gas treatment system operates 365 days a year and treats off-gas from the 2000-MTHM/yr FRP and its storage basin.

4.10.2

- The design volumetric flow is approximately 139 m³/min (4900 ft³/min).
- The facility is incorporated as an integral part of the FRP.
- The system is designed to achieve a decontamination factor (DF) of 10³ for particulate ruthenium and other particles, 10¹ for volatile ruthenium, and 10³ for iodine.

TABLE 4.10.1. Fuel Reprocessing Plant Vessel Off-Gas^(a,b)

Component	Annual Quantity, kg	Radioactivity, Ci/yr	
H ₂ O	4.4 x 10 ⁵	<u>Fission Products</u>	
I	2.4	³ H	8.4 x 10 ²
Air	9.4 x 10 ⁷	¹²⁹ I	3.5 x 10 ⁻¹
NO _x	5.5 x 10 ²	⁸⁵ Kr	1.7 x 10 ¹
		⁹⁰ Sr + ⁹⁰ Y	2.4 x 10 ¹
		⁹⁵ Zr + ⁹⁵ Nb	2.2
		¹⁰⁶ Ru + ¹⁰⁶ Rh	7.6 x 10 ¹
		¹³⁴ Cs + ¹³⁷ Cs	
		+ ^{137m} Ba	6.0 x 10 ¹
		¹⁴⁴ Ce + ¹⁴⁴ Pr	9.6 x 10 ¹
		All Other	2.0 x 10 ¹
		Total	1.1 x 10 ³
		<u>Actinides</u>	
		²³⁹ Pu	7.2 x 10 ⁻²
		²⁴¹ Pu	3.5 x 10 ¹
		Other Pu	1.2
		²⁴² Cm + ²⁴⁴ Cm	3.4
		All Other	1.8 x 10 ⁻¹
		Total	4.0 x 10 ¹

a. Based on waste characterization Table 3.3.27
assuming uranium and plutonium recycle, 2000 MTHM/yr
reprocessed 1.5 years out of reactor.

b. Volume = 7.3 x 10⁷ m³/yr.

4.10.1.3 Vessel Off-gas Treatment Process at the Fuel Reprocessing Plant

Figure 4.10.1 is a process flowsheet for the VOG system; the material balance is given in Table 4.10.2. The iodine recovery process portion of the flowsheet is described in Section 4.9.1 and is based on both bench-scale and plant operating experience.⁽²⁾ The NO_x removal process is described in Section 4.9.2. Table 4.10.3 lists the major components of the VOG system and summarizes their function.

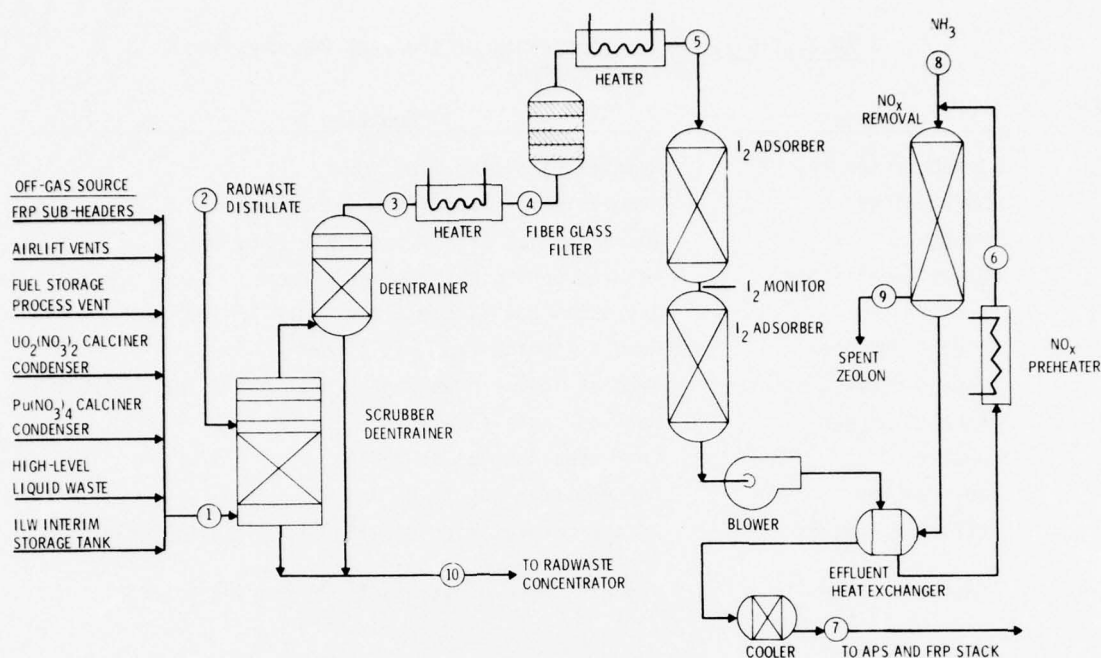


FIGURE 4.10.1. Process Flow Diagram for Fuel Reprocessing Plant Vessel Off-gas System (Circled numbers refer to stream numbers given in Table 4.10.2.)

TABLE 4.10.2. Material Balance for Fuel Reprocessing Plant Vessel Off-gas System

Stream Number	Temperature, °C	Total Flow, m3/hr	Total Flow, kg/hr	Flow by Components, kg/hr										Solid Waste, m3/yr
				N	O	Ar	CO ₂	H ₂ O	I	Kr	NO _x	NO ₂	NH ₃	
1	35	8,340	10,783	8,111	2,480	137	5.4	50	3 x 10 ⁻⁴	Trace	0.07			
2	35		1,000					1,000						
3	35	9,020	10,944	8,111	2,480	137	5.4	211	3 x 10 ⁻⁴	Trace	0.07			
4	45	9,313	10,944	8,111	2,480	137	5.4	211	3 x 10 ⁻⁴	Trace	0.07			
5	150	12,385	10,944	8,111	2,480	137	5.4	211	3 x 10 ⁻⁴	Trace	0.07			
6	350	18,245	10,944	8,111	2,480	137	5.4	211	3 x 10 ⁻⁷	Trace	0.07			
7	35	9,020	10,944	8,111	2,480	137	5.4	211	3 x 10 ⁻⁷	Trace	3 x 10 ⁻⁵	3 x 10 ⁻³		
8	300		0.03										0.03	
9														
10	35		839					839						7.5

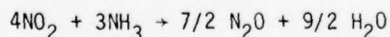
Gaseous emissions from the various process vessels and from the FRP spent fuel storage basin are collected in subheaders and are fed to the bottom of the off-gas scrubber-deentrainer. In the scrubber section, the gas stream is contacted with 17 l/min of water from the radioactive waste distillate system. The scrubber-deentrainer, along with a second deentrainer, remove entrained water droplets to protect the glass fiber filters and iodine adsorbers. Water vapor is reduced to less than 3 vol%. The bottoms stream from the scrubber and deentrainers is recycled to the radioactive waste concentrator. The particle DF is assumed to be 10² for the scrubber-deentrainer. No DF is assumed for iodine although partial removal is expected.

TABLE 4.10.3. Major Components of the Fuel Reprocessing Off-gas System

Name	Function
Scrubber-deentrainer	Removes particles from VOG
Deentrainer	Removes water vapor from gas stream
Heater	Increases gas stream temperature to 45°C
Glass fiber filter	Removes particles from gas stream
Heater	Increases gas stream temperature to 150°C
Iodine adsorber	Removes iodine from gas stream
Iodine back-up adsorber	Retains iodine breaking through on iodine adsorber
Exhaust blower	Motivates gas flow
Heater	Increases the gas to 350°C
NO _x reactor	Converts the NO _x to N ₂ and H ₂ O
Effluent heat exchange	Heat recovery prior to exhausting gas to cooler and APS
Cooler	Reduces the exhaust gas to 35°C prior to APS

The off-gas stream exiting the top of the second deentrainer is heated to 45°C by an electric heater and passed through a packaged glass fiber high-efficiency filter to remove additional particulate matter ($DF = 10^1$). The gas is then heated to 150°C and passed through the iodine recovery system ($DF = 10^3$), which contains a silver-impregnated adsorbent. The gas from the iodine recovery system is partially heated by the exit gas from the NO_x reactor and then passed through another electric heater, which raises the gas temperature to that required for operation of the NO_x removal system (about 350°C). The gas exits the heater and flows downward through the NO_x reactor. After passing through the NO_x removal subsystem, the gas is cooled to about 35°C in a heat exchanger and cooler before being released to the APS.

The NO_x composition in the vessel off-gas stream is about 7×10^{-4} wt% but varies considerably because of the variety of incoming off-gases. No NO_x decontamination is assigned to the off-gas scrubber-deentrainer because of the low concentration of the incoming gas. The NO_x system⁽³⁾ removes 99.9% of the NO_x in the VOG by reacting ammonia with the oxides of nitrogen in the presence of a synthetic mordenite catalyst at temperatures of about 350°C. Some N₂O is produced as a result of a competing reaction:



This reaction is dependent on temperature and on the water content of the gas. By keeping the temperature at or above 350°C and the water content of the gas below 3%, less than 10% of the influent NO₂ should be converted to N₂O. None of the NO reacts to form N₂O.

The NO_x system functions continuously while the plant is in operation. Two independently piped NO_x preheaters and NO_x reactors are available, with one in use and one as a spare. A high-pressure drop across one reactor is sensed by a differential pressure sensor across the .

4.10.5

inlet and outlet of the bed, which switches the flow automatically to the second bed. If plugging occurs in either of the packed-bed NO_x removal vessels, the vessel must be removed and replaced. This requires the use of flanges on the inlet and outlet of each bed. Provision is made to replace burnt-out electrical resistance elements in the NO_x preheater.

During vessel off-gas system operation, the deentrainers occasionally plug and require washing with water or acid; spray nozzles are installed in the deentrainers for that purpose. It is recommended that the deentrainers be washed when the mesh pad pressure drops to three times the nominal pressure drop (ΔP). A nominal ΔP of 5 cm H_2O is estimated for the scrubber-deentrainer. The nominal ΔP for the second deentrainer is 3 cm H_2O . A wash solution flow of about 27 ℓ/min would be required to unplug the former and a flow of 72 ℓ/min to unplug the latter.

The iodine beds are operated until iodine is detected on the exit side of the cartridge. At this breakthrough, the radiation monitors alarm and the gas flow is switched to the parallel system.

4.10.1.4 Facility Description for the Vessel Off-gas System

Figure 4.10.2 shows the approximate location within the FRP of the facility that houses the vessel off-gas system. A plan and section views of the VOG facility are shown in Figures 4.10.3, 4.10.4, and 4.10.5.

The VOG facility shares FRP services, utilities, laboratories, health physics support, personnel change areas, maintenance areas, warehousing, shops and offices. The facility is housed within three cells, one remote and two contact. The packed glass fiber filter, which will probably last the life of the plant, is in the remote cell. Other particle and iodine removal equipment is in one contact cell, and the NO_x destruction equipment is in the other. Gas blowers are in individual, shielded niches outside the cells. Shielded labyrinth entries to the contact-maintained process areas are used for personnel access. Hatches in the ceilings of the cells are provided for major equipment access; an overhead bridge crane is used in the area above the cells.

All process equipment is enclosed within Category I cells and galleries, constructed of reinforced concrete. Cells are provided with floor liners, sumps and protective coatings to facilitate decontamination. The facilities for the VOG system are, in turn, enclosed within the outer walls of the Category I FRP structure. The area above the cells is structural steel with insulated metal walls and roof.

Scrubber-Deentrainer. The deentrainment portion of the scrubber and mist eliminator has a 1-m diameter. This provides face velocity of 200 m/min in a coarse mesh pad (of austenitic stainless steel) in the top of the column that removes approximately 99% of the entrainment.

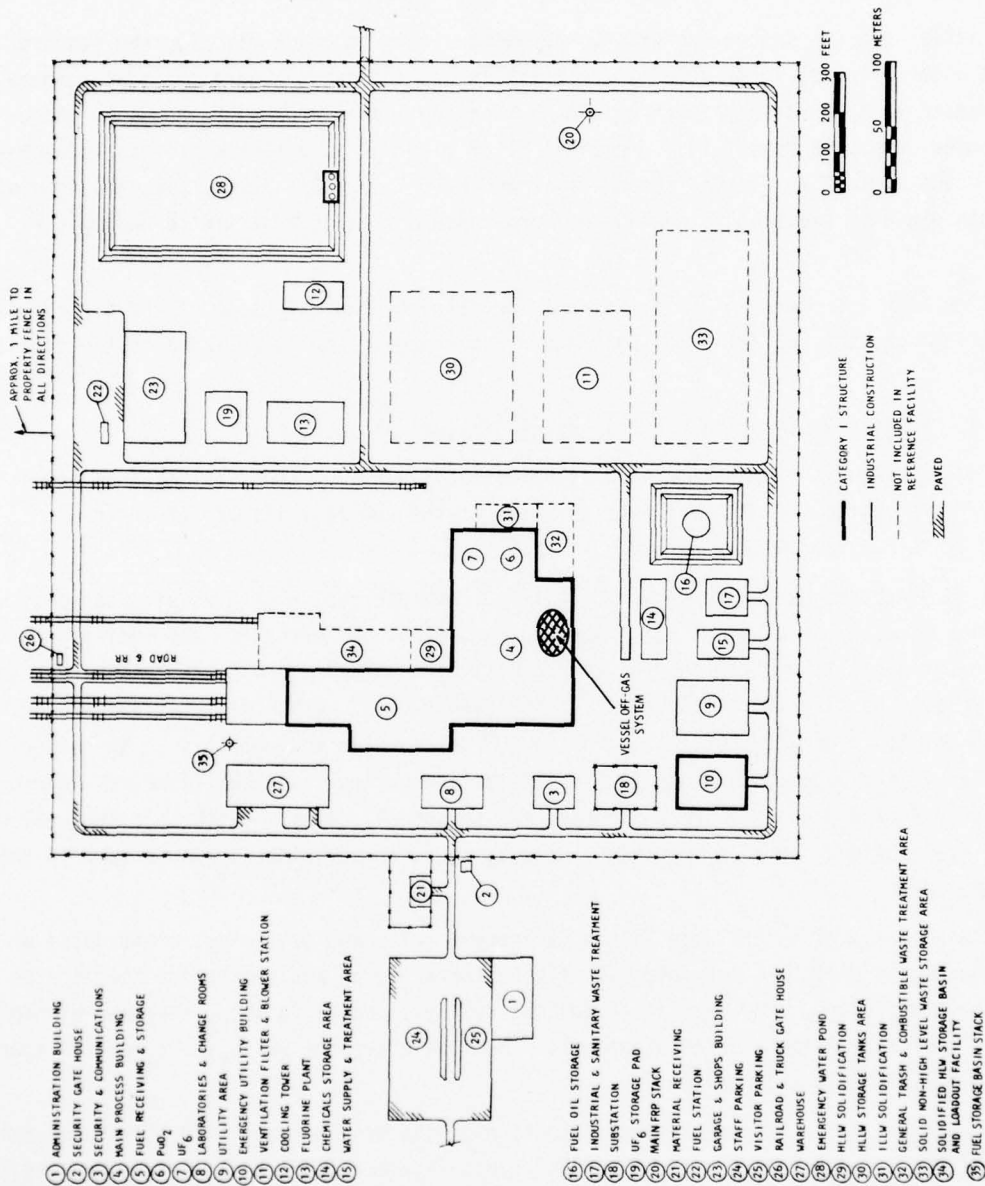


FIGURE 4.10.2. Approximate Location of Facility for Vessel Off-gas Treatment Within the Fuel Reprocessing Plant

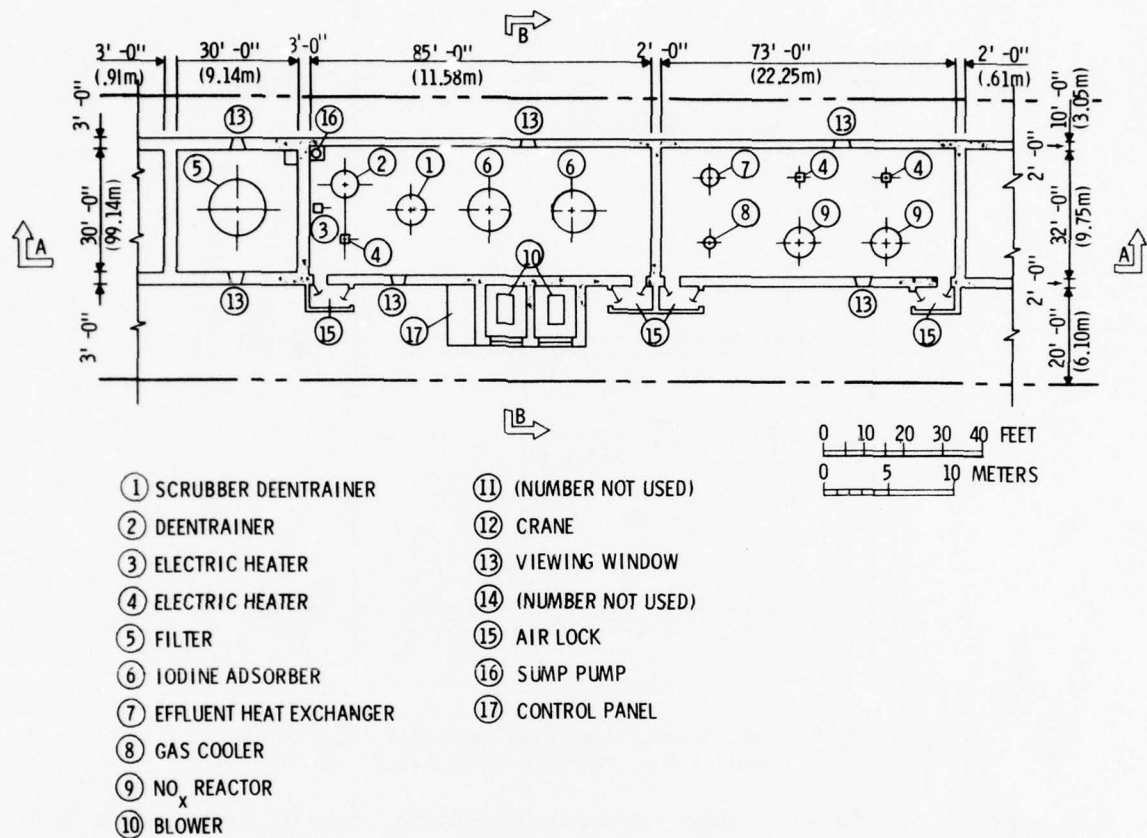


FIGURE 4.10.3. Fuel Reprocessing Plant Vessel Off-gas System, General Plan

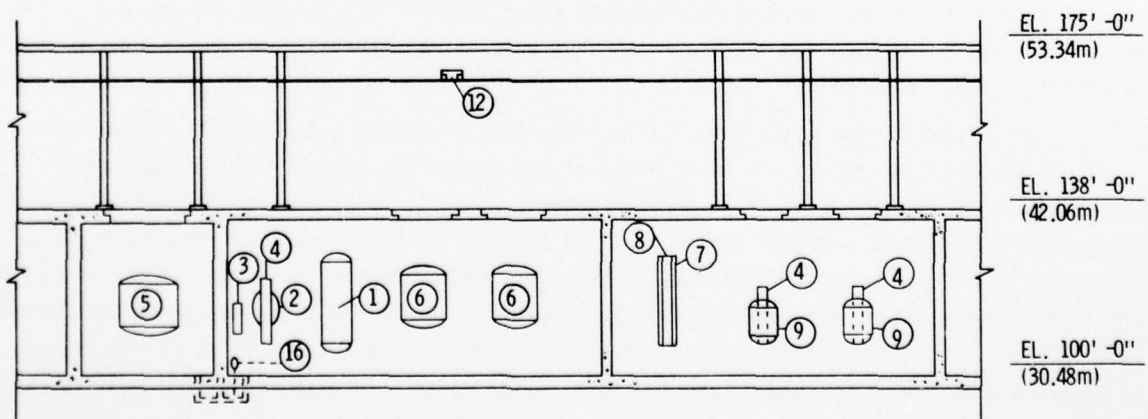


FIGURE 4.10.4. Fuel Reprocessing Plant Vessel Off-gas System, Section A-A (See Figure 4.10.3 for number key.)

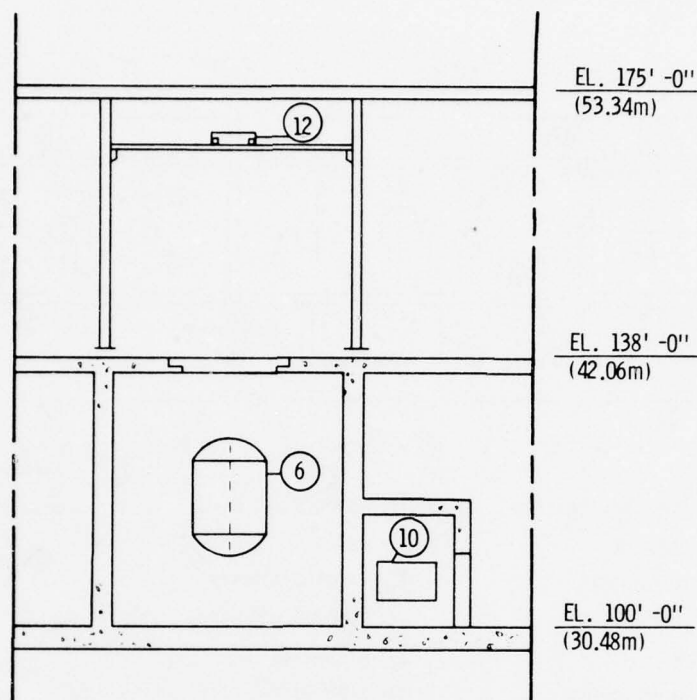


FIGURE 4.10.5. Fuel Reprocessing Plant Vessel Off-gas System
Section B-B (See Figure 4.10.3 for number key.)

Deentrainer. Figure 4.10.6 shows the second deentrainer in the VOG system. This deentrainer is a high-efficiency type contained in its own vessel. Its removal efficiency is 99.8% for droplet sizes up to $3\text{ }\mu\text{m}$. A design face velocity of 75 m/min is achieved using a 1.5-m diameter vessel. The mesh pad is located 75 cm from the bottom of the vessel, which has an overall height of 100 cm . Austenitic stainless steel construction is required because of the acid conditions. The pads are fabricated of fine metal wire; typically, titanium wire is used in stainless steel equipment.

Off-gas Heaters. The glass fiber filter, the iodine adsorber, and the NO_x reactor each require a preheater to adjust the temperature of the inflow gas stream. Present design of these heaters is limited to their power requirements. The filter preheater is controlled to give a 10°C temperature increase to the gas. It requires 30 kW of power during normal operation and a design heater installation of 45 kW . The iodine adsorber preheater is controlled to give 150°C in the outlet and requires a nominal heat load of 140 kW and a design heater installation of 200 kW . The NO_x preheater is automatically controlled to give 350°C in the outlet; it requires a nominal heat load of 150 kW and a design heater installation of 200 kW . Austenitic stainless steel construction is recommended for all three heaters.

Packaged Glass Fiber Filter. The glass fiber filter (Figure 4.10.7) is a tank-type⁽⁴⁾ structure containing layers of glass fiber filter medium. Fiber glass is used because of its resistance to corrosive nitric acid vapors. The glass fiber has a diameter of $20\text{ }\mu\text{m}$ and is bulk-packed in layers to densities ranging from 25 kg/m^3 (1.5 lb./ft^3) at the gas inlet to

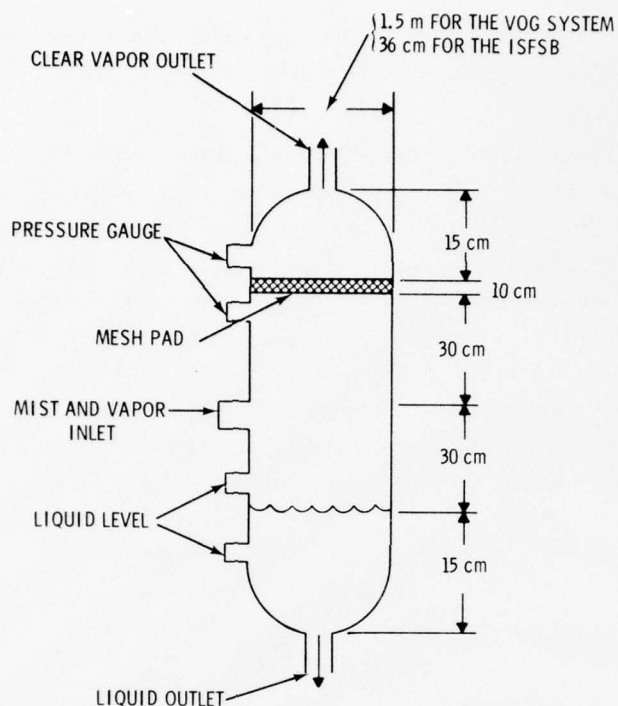
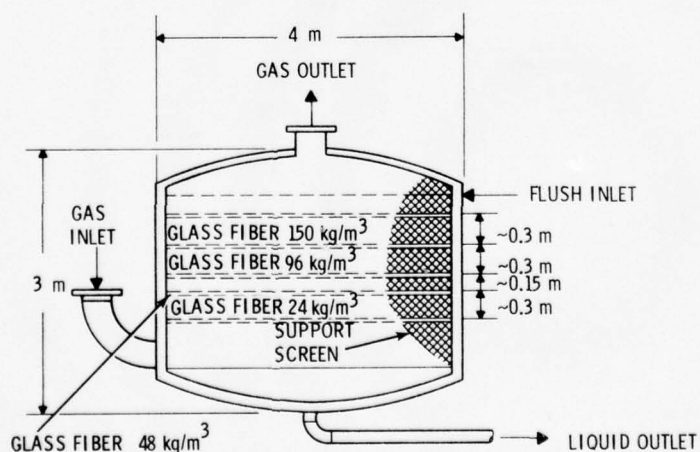


FIGURE 4.10.6. Iodine Absorption Subsystem Deentrainer

FIGURE 4.10.7. Glass Fiber Off-gas Filter⁽⁴⁾

150 kg/m³ (1.5 to 9 lb/ft³) at the gas outlet. Wire mesh separates each layer. The unit is 4 m in diameter and is designed for a superficial flow velocity of 5 to 15 m/min (15 to 50 ft/min) and for a particle retention efficiency of about 99% for 0.7- μ m particles. The design permits high filtration efficiency, high particulate loadings and long service life. The unit

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is equipped with backflush (radioactive waste recycle water) and drain lines to permit partial decontamination and reduction of pressure drop without removal. The unit is assumed to serve for the life of the FRP.

Iodine Adsorbers. Figure 4.10.8 shows a typical iodine adsorber.⁽⁴⁾ The halogen inventory in the vessel off-gas is about 2350 g of iodine per year. The adsorbent train provides an iodine decontamination factor (DF) of 10^3 , and is the only iodine recovery method provided for in the VOG system. The adsorbent is silver-zeolite, containing 12 wt% silver, and has a dry density of 0.68 g/cm^3 . The adsorbent is held in place by wire mesh screen over a metal grid. The adsorber bed is designed for a superficial flow velocity of about 15 m/min (50 ft/min) with a 4-m (13 ft) diameter 304L stainless steel vessel. The bed is 1 m (3.3 ft) deep and contains 12.6 m^3 (444 ft^3) of the silver-zeolite, weighing $8.6 \times 10^3 \text{ kg}$. An 80% bed loading is used to give an average loading of 0.08 g of iodine per cm^3 . The iodine adsorber is assumed to serve for the life of the plant; however, actual experience may require more frequent replacement.

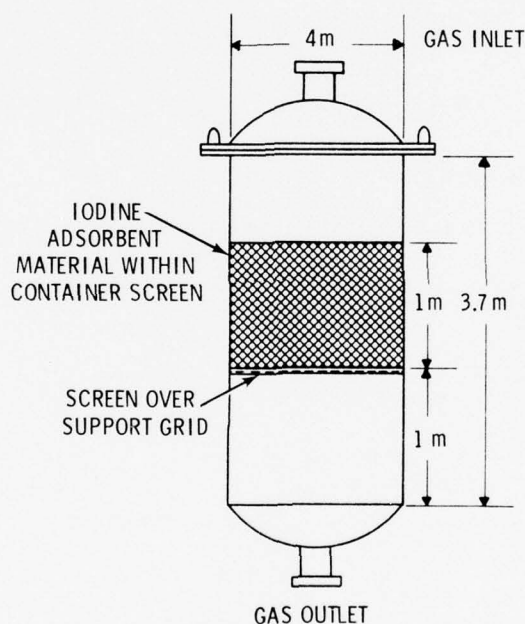


FIGURE 4.10.8. Iodine Adsorber⁽⁴⁾

Two iodine adsorbers are used in series so that failure of one will not result in a significant increase in iodine released to the environment. Each adsorber is equipped with an iodine monitor to detect breakthrough. The iodine-129 samplers are positioned before and after the primary and back-up iodine adsorbers. The sampling systems comprise small heated beds of silver-zeolite positioned on top of lithium-drifted germanium detectors; these detectors measure the 30 keV x-ray from iodine-129. A fraction of the off-gas stream is drawn continuously through the sampling system; however, the samplers must be evacuated to remove krypton-85 prior to measurement. A multichannel analyzer with sequential switching is used to monitor a given sampler at a desired frequency.

4.10.11

NO_x Reactor. The NO_x reactor is 3 m (9.8 ft) in diameter and 1.8 m (6 ft) high. The reactor contains 5100 kg (11,000 lb) of catalyst (synthetic mordenite) bed. Both inlet and outlet lines are 0.4 m (15 in.) in diameter. The vessel is designed for a pressure of 30 psig and a temperature of 460°C. The shell, heads, and internals are constructed of 321 stainless steel.

Shielding and Remote Handling Equipment. Two of the facility's cells are contact maintained; one is remotely maintained. Shielded labyrinth entries to the process area are used for personnel access to the contact-maintained cells. Dose rates are limited to less than 1 mrem/hr, and during entry total exposure is rigorously controlled. For sorbent replacement, the large volume of sorbent may require remote transfer to storage barrels.

4.10.1.5. Vessel Off-gas System Operating and Maintenance Requirements

The VOG system operates as part of the FRP 24 hours a day, 7 days a week, 365 days a year. Normal activities include monitoring the iodine, scrubber, and NO_x systems, and routine equipment maintenance and replacement.

Staffing. Estimated staffing requirements for the VOG facility are shown in Table 4.10.4.

TABLE 4.10.4. Fuel Reprocessing Plant Vessel Off-gas System Staffing Requirements

<u>Job Description</u>	<u>Personnel Required, man-yr/yr</u>
Operators	2
Radiation monitors	1
Maintenance craftsmen	2

Supplies and Utilities. Table 4.10.5 shows the supplies used in the FRP vessel off-gas system. Estimated utility requirements are shown in Table 4.10.6.

TABLE 4.10.5. Fuel Reprocessing Plant Vessel Off-gas System Supply Requirements

<u>Supply</u>	<u>Use</u>	<u>Annual Requirement</u>
Zeolite ^(a)	NO _x removal	12.6 m ³
NH ₃	NO _x removal	216 kg

a. Removed only when necessary.

TABLE 4.10.6. Fuel Reprocessing Plant Vessel Off-gas System Utility Requirements

Utility	Use Rate	Annual Requirement
Electricity	500 kW	2.3×10^6 kWh
Steam	500 kg/hr	3.6×10^6 kg
Water consumed	$1.6 \text{ m}^3/\text{hr}$	$1.2 \times 10^4 \text{ m}^3$

4.10.1.6 Vessel Off-gas System Secondary Radioactive Wastes

Estimates of secondary radioactive wastes associated with the reference facility are shown in Table 4.10.7.

TABLE 4.10.7. Fuel Reprocessing Plant Vessel Off-gas System Secondary Radioactive Wastes

Description	Volume, m^3/yr	Radioactivity Factor ^(a)
Combustible and compactable waste	80	1×10^{-5}

a. Fraction of input activity (Table 4.10.1, excluding volatiles) in secondary wastes.

4.10.1.7 Vessel Off-gas System Emissions

Facility emissions are characterized in Table 4.10.8.

4.10.1.8 Vessel Off-gas System Decommissioning Considerations

The facility housing the FRP vessel off-gas system is designed to be functional for the life of the plant. The cells are provided with floor liners, sumps and protective coatings to facilitate decontamination. The glass fiber packed filter and the silver-zeolite column will probably last for the life of the plant and will be part of the FRP decommissioning waste. It is expected that at the end of the FRP facility's operating life the vessel off-gas facility will be relatively free of contamination, with the exception of the iodine-loaded silver-zeolite column.

4.10.1.9 Postulated Accidents of the Plant Vessel Off-gas System

Scenarios of postulated accidents for the FRP vessel off-gas system are listed in Tables 4.10.9 and 4.10.10. One of the postulated minor accidents is identical to Accident 4.9.1 described in Table 4.9.9 for the FRP dissolver off-gas system. No accidents that could be classified as severe accidents could be realistically postulated for this technology.

TABLE 4.10.8. Fuel Reprocessing Plant Vessel Off-gas System Emissions

Emission	Description	Annual Quantity		Radioactivity Release Factor to Atmosphere ^(a)	
Gaseous	Vessel Off-gas	Air	$7.7 \times 10^7 \text{ m}^3$	^3H	1.0 ^(b)
		N_2O	$2.1 \times 10^1 \text{ kg}$	^{85}Kr	1.0
		NO_x	$2.5 \times 10^{-1} \text{ kg}$	$^{106}\text{Ru-Rh}$	5×10^{-2} ^(c)
				^{129}I	1×10^{-3}
				All others	1×10^{-7}
		Minor accident, integrated annual release		Included in operational release	
Cooling tower water:	evaporated				
	$T = 38^\circ\text{C}$		$1.0 \times 10^7 \text{ kg}$		
	drift				
	$T = 38^\circ\text{C}$		$5.0 \times 10^4 \text{ kg}$		
	blowdown				
	$T = 27^\circ\text{C}$		$1.8 \times 10^6 \text{ kg}$		
Other	heat		$6.7 \times 10^3 \text{ MW-hr}$		
			$(2.4 \times 10^{10} \text{ Btu})$		

- a. Fraction of input activity (Table 4.10.1) released to atmosphere. Includes DF from main plant APS where applicable. Released over 365 days/year.
- b. A portion of the tritium will be removed from the vessel off-gas and released via the FRP excess water vaporizer.
- c. Assumes that the volatile ruthenium is not converted to particulate ruthenium by the time it reaches the APS.

TABLE 4.10.9. Minor Accidents of the Fuel Reprocessing Plant Vessel Off-gas System

Accident No. and Description	Sequence of Events	Safety Systems	Release
4.10.1 - Plugged iodine bed.	See Accident 4.9.1 in Table 4.9.9, Section 4.9.1		None
4.10.2 - Packaged glass fiber filter breached.	1. Filter media damaged because of improper installation.	1. Filter DOP tested before and after installation.	None.
	2. Loss of filtration noted by alarm.	2. Radiation and airflow monitoring systems provide continuous monitoring.	
	3. Filter system is by-passed.	3. The off-gas continues to be filtered by the APS before being released.	
	4. FRP shutdown.	4. The packaged filter can be replaced during FRP shutdown.	
	5. Damaged filter is replaced.		

TABLE 4.10.10. Moderate Accidents of the Fuel Reprocessing Plant Vessel Off-gas System

Accident No. and Description	Sequence of Events	Safety Systems	Release
4.10.3 - VOG system shutdown.	1. Both iodine adsorbers fail.	1. Radiation and airflow monitoring is continuous.	If the VOG is vented to the main stack, which has a gas flow of $4 \times 10^5 \text{ m}^3/\text{hr}$, the iodine release concentration would be $1 \times 10^{-10} \text{ } \mu\text{Ci}/\text{cm}^3$. This is below the maximum permissible concentration for soluble and insoluble species in air.
	2. Radiation and airflow monitors detect venting to FRP APS.	2. Receipt of additional fuel in the storage facility limited until repairs in the FRP are completed.	
	3. FRP fuel storage facility continues to operate.	3. Dissolver is shut down after processing material in dissolver.	
	4. Dissolver and main FRP process shutdown. FRP continues to process until out of dissolver solution.	4. FRP remains down until repairs are completed.	
		5. FRP fuel storage facility limits activities to reduce process off-gas to minimum.	

4.10.1.10 Facility Costs for the Vessel Off-gas System

Estimates have been made, in mid-1976 dollars, of capital, operating and levelized unit costs. A complete description of the cost estimate bases, assumptions and definitions is given in Section 3.8.

Capital Costs. The capital cost estimate for the FRP vessel off-gas treatment facility is shown in Table 4.10.11. The estimate covers all capital costs specifically resulting from the inclusion of the VOG treatment facility as an integral part of the primary reference FRP. It also includes the costs of incremental additions to HVAC and to utilities, such as electrical supply from the substation, steam, water, and compressed air, as well as bulk materials for piping, electrical and instrument tie-ins with the primary FRP. A portion of shared galleries outside the process cells and central control room space is also included as part of the incremental additions. No allocation is made of general FRP costs for such services as laboratories, personnel facilities, health physics, warehousing, shops, administration building, and so on.

The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation, with the exception of working capital.

TABLE 4.10.11. Capital Cost Estimate for the Fuel Reprocessing Plant Vessel Off-gas System

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		7	1,350	90	1,440
Buildings and structures		360	1,780	4,310	6,090
Bulk materials		85	1,680	1,020	2,700
Site improvements		--	--	--	--
Subtotal of direct site construction costs		452	4,810	5,420	10,230
Indirect site construction costs	120	90	1,980	2,630	4,610
Total field cost	120	542	6,790	8,050	14,840
Architect-engineer services					2,660
Subtotal					17,500
Owner's cost					5,300
Total facility cost					22,800
Estimate accuracy range					±25%

Operating Costs. Direct labor costs are based on the manpower schedule shown in Table 4.10.4. Process material costs are based on requirements shown in Table 4.10.5. The cost of silver-zeolite, estimated at \$110/kg, is a one-time charge in the first year of facility operation. Utility costs are based on requirements given in Table 4.10.6. Table 4.10.12 shows the operating cost breakdown. Maintenance materials costs are estimated at 5% of major equipment costs.

TABLE 4.10.12. Operating Cost Estimate for the Fuel Reprocessing Plant Vessel Off-gas System

Cost Element	Annual Costs, \$1000s	
	First Year	Subsequent Years
Direct labor	80	80
Process materials (silver-zeolite)	1,880	0
Utilities	60	60
Maintenance materials	40	40
Overhead	100	100
Miscellaneous	70	70
Total	2,230 ±25%	350 +50% -25%

Levelized Unit Costs. The levelized unit cost, including the levelized capital and operating charges, is shown in Table 4.10.13. The unit cost calculation assumes private ownership of the facility and a 15-year economic life.

TABLE 4.10.13. Levelized Unit Cost Estimate for the Fuel Reprocessing Plant Vessel Off-gas System

<u>Cost Element</u>	<u>Unit Cost, \$/kg HM</u>
Levelized capital charge	2.80
Levelized operating charge	<u>0.50</u>
Levelized total unit cost	3.30 ±35%

4.10.1.11 Vessel Off-gas System Construction Requirements

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating the impact of construction activities.

Project Schedules and Construction Manpower. The schedule for engineering, procurement and construction of the VOG system is an integral factor in the overall schedule for the FRP. The field labor force estimated for the construction of the facility in which the vessel off-gas system is housed is tabulated below:

	<u>Man-hours, 1000s</u>
Manual field labor	542
Nonmanual field labor	<u>120</u>
Total field labor	662

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials and services provided at the site of the FRP, while offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is:

	<u>Costs, \$1000s</u>
Onsite	8,600
Offsite	<u>14,200</u>
Total	22,800

Site Requirements. The VOG will share the same site as the FRP. No additional site requirements beyond those for FRP are identifiable. Land commitments for the VOG are included with those of the FRP.

4.10.17

Water. Water used during the construction period is estimated at 8000 m^3 ($2.1 \times 10^6 \text{ gal}$).

Construction Materials. Materials committed to construction are:

Concrete	2,500 m^3	(3,200 yd^3)
Steel	500 MT	(550 tons)
Copper	2.7 MT	(3 tons)
Zinc	negligible	
Aluminum	negligible	
Lumber	94 m^3	(40 MFBM)

Energy. Energy resources used during construction are:

Propane	76 m^3	(20,000 gal)
Diesel	760 m^3	(200,000 gal)
Gasoline	490 m^3	(130,000 gal)
Electricity		
Peak demand	300 kW	
Total consumption	380,000 kWh	

Transportation Requirements. No transportation requirements for the VOG system have been identified beyond those for the FRP.

4.10.1.12 Effects of Fuel Cycle Options

The reference process for the FRP vessel off-gas system assumes reprocessing of LWR fuel and recycling the retrieved uranium and plutonium. The following alternative fuel cycle modes have also been assessed insofar as they relate to vessel off-gas treatment at the FRP.

No Recycle. Eliminating the fuel reprocessing operation does away with the generation of dissolver and process off-gases. Accordingly, no off-gas system is required. If spent fuels are being stored at the FRP, a process off-gas system would be required as described in Section 4.10.2.

Uranium Recycle Only, with Plutonium to a Repository. This alternative is expected to generate about the same amount of dissolver and process off-gas as in the uranium and plutonium recycle case.

Uranium Recycle Only, with Plutonium to HLW. This alternative would generate about the same quantity of dissolver and process off-gas as in the uranium and plutonium recycle case.

4.10.2 Process Off-gas Treatment at an Independent Spent Fuel Storage Basin

A process off-gas (POG) system at the reference independent spent fuel storage basin (ISFSB) is provided to treat off-gas from cask venting, leaking fuel assemblies, and other areas with high potential for release of gaseous fission products. The process includes systems for iodine and particle removal.

4.10.2.1 Alternative Process Off-gas Treatment Methods

Iodine recovery process alternatives have been described in Section 4.9.1 and apply to process off-gas treatment at the ISFSB. Alternative particle removal systems have been described in Section 4.8.

4.10.2.2 Process Off-gas System Design Basis

Table 4.10.14 gives the design basis off-gas composition and lists the components, the annual quantity, and the radioactivity factors associated with the feed stream. The following assumptions were made in the design of the reference POG system:

- The POG treatment system operates 365 days/yr and treats off-gas from a 3000-MTHM/independent fuel storage basin.
- The design volumetric flow is approximately $7 \text{ m}^3/\text{min}$ ($245 \text{ ft}^3/\text{min}$).
- The facility is designed as an integral part of the storage basin.
- The facility recovers only iodine and particles.

TABLE 4.10.14. Independent Spent Fuel Storage Basin
Process Off-gas System Feed Activity^(a,b)

Component	Annual Quantity, kg	Radioactivity, Ci/yr	
H ₂ O	2.5×10^4	³ H	0.34
Air	4.8×10^6	¹⁴ C	8.4×10^{-4}
I	4.7×10^{-3}	⁸⁵ Kr	2.2×10^2
		¹²⁹ I	2.1×10^{-4}
		All others 0	

- a. Based on waste characterization Table 3.3.23, assuming uranium and plutonium recycle, 3000 MTHM in storage, average of 3.5 yr out of reactor.
- b. Volume = $3.7 \times 10^6 \text{ m}^3/\text{yr}$.

4.10.2.3 Process Off-gas Treatment Process

A process flowsheet for the reference POG system is shown in Figure 4.10.9. Table 4.10.15 gives the material balance. Table 4.10.16 lists the major components of the POG system and summarizes their functions.

Radioactive gaseous emissions from the cask venting and cool-down system and from leaking fuel in the independent spent fuel storage basin are collected and routed to the off-gas scrubber-deentrainer. Most of the particles are removed in the scrubber section, where the off-gas stream is contacted with about 1 l/min of water recovered in the radioactive waste distillate system. The scrubber-deentrainer and a second deentrainer are used to protect the high-efficiency particulate air (HEPA) filter and iodine adsorbers from entrained water droplets. Water vapor is reduced to less than 5 vol% by the deentrainers; the spent solution, containing some of the iodine and particles is recycled to the radioactive waste concentrator.

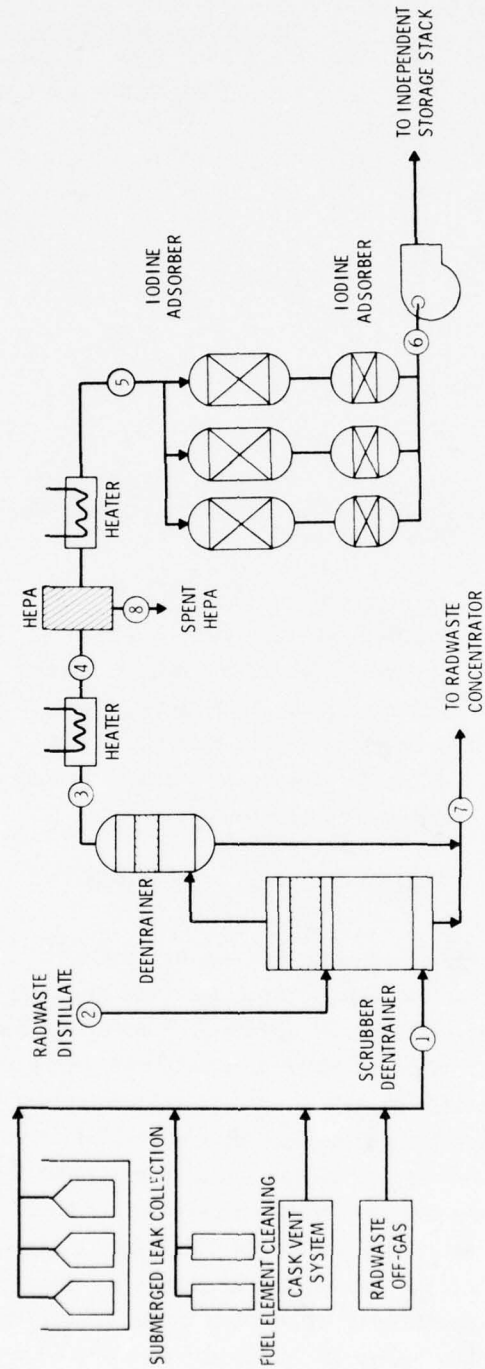


FIGURE 4.10.9. Flowsheet for the Independent Spent Fuel Storage Basin Process Off-gas System (Circled numbers refer to stream numbers given in Table 4.10.15.)

TABLE 4.10.15. Material Balance for the Independent Spent Fuel Storage Basin Process Off-gas System

Stream Number	Temperature, °C	Total Flow, m ³ /hr	Total Flow, kg/hr	Flow by Components, kg/hr							Solid Waste, m ³ /yr
				N	O	Ar	CO ₂	H ₂ O	I	Kr	
1	35	425	552	415	127	7.0	0.28	2.8	5.4 x 10 ⁻⁷	trace	
2	35		60					60			
3	35	460	560	415	127	7.0	0.28	11	5.4 x 10 ⁻⁷	trace	
4	45	475	560	415	127	7.0	0.28	11	5.4 x 10 ⁻⁷	trace	
5	150	632	560	415		7.0	0.28	11	5.4 x 10 ⁻⁷	trace	
6	150	632	560	415	127	7.0	0.28	11	5.4 x 10 ⁻¹⁰	trace	
7	35		52					52			
8											0.3 ^(a)

a. Replaced when necessary (~ 12 months).

TABLE 4.10.16. Major Components of the Independent Spent Fuel Storage Basin Process Off-gas System

Name	Function
Scrubber-deentrainer	Removes particles from POG
Deentrainer	Removes water vapor from gas stream
Heater	Increases gas stream temperature to 45°C
HEPA	Removes particles from gas stream
Heater	Increases temperature of gas stream to 150°C
Iodine adsorber	Removes iodine from gas stream
Iodine backup adsorber	Retains iodine breaking through on iodine adsorber

The off-gas stream exiting the top of the scrubber and deentrainers is heated to 45°C by an electric heater and is passed through a prefilter and a fiber glass HEPA filter to remove any remaining particulate matter. The gas is then heated again to 150°C and finally sent through the iodine recovery system, which contains a silver-impregnated adsorbent. Heating the air stream prevents condensation of water vapor in the downstream components. Elemental iodine and methyl iodide are adsorbed on the packed, silver-zeolite adsorber bed. The gas stream leaving the iodine recovery system is continuously monitored for radioactivity; it is combined with the ventilation air and sent to the independent stack. The iodine recovery portion of the flowsheet has been described in Section 4.9.1 and is based on both bench-scale and plant-scale operating experience.⁽²⁾ The removal of particles using HEPA filters has been described in Section 4.8. The particle DF is assumed to be 10³ for the HEPA filter and 10² for the scrubber-deentrainer. The iodine DF is assumed to be 10³ for the silver-zeolite adsorber bed.

During operation the deentrainers occasionally plug and require washing with water or acid, using the spray nozzles installed for that purpose. Washing is recommended when a mesh pad pressure drop (ΔP) of three times the nominal ΔP occurs. A nominal ΔP of 5 cm H_2O has been estimated for the scrubber-deentrainer. The second deentrainer has a nominal ΔP of 3 cm H_2O . A wash solution flow of 1.3 ℓ/min is required to unplug the former, and a flow of 4 ℓ/min to unplug the latter.

4.10.2.4 Facility Description for the Process Off-gas System

The process off-gas system is an integral part of the independent spent fuel storage basin. The approximate location of system facilities is shown on the plot plan for the ISFSB, Figure 4.10.10. Plan and section views of the process off-gas system are shown in Figures 4.10.11 and 4.10.12.

The POG system shares the ISFSB services, utilities, laboratories, health physics support, personnel change areas, maintenance areas, warehousing, shops and offices. The system, including all its process equipment, is housed within a contact-maintained cell. Shielded labyrinth entries to the POG process area are used for personnel access. A roof hatch is provided for equipment removal. An overhead bridge crane within the facility is available for handling the iodine adsorber cartridges and for equipment transfer and maintenance.

As a Category I, reinforced concrete structure, the cell is both earthquake- and tornado-resistant. It is provided with a stainless steel floor pan, a sump, and protective coatings to facilitate decontamination. The cell is located within the outer walls of the Category I ISFSB structure. Major pieces of equipment within this facility are described below.

Scrubber-Deentrainer. The deentrainment portion of the scrubber and mist eliminator has a 22-cm diameter, which gives a face velocity of 200 m/min in a coarse mesh pad (titanium wire) in the top of the column. This removes approximately 99% of the entrainment.

Deentrainer. The second deentrainer used in the POG system is identical to that shown in Figure 4.10.6 for the fuel reprocessing plant vessel off-gas system. This deentrainer is a high-efficiency type contained in its own vessel. It gives 99.8% removal efficiency for droplet sizes up to 3 μm . A design face velocity of 75 m/min is achieved using a 36-cm diameter vessel. The mesh pad is located 75 cm from the bottom of the vessel, which has an overall height of 100 cm. Austenitic stainless steel construction is required because of the acid conditions. The pad deentrainer is fabricated of fine metal wire; typically, titanium wire is used in stainless steel equipment.

Filter Preheater. The filter preheater is an electric heater requiring 1.5 kW of power during normal operation. Heater design capacity is 2.5 kW. This heater is controlled to increase the temperature of the off-gas by 10°C. Austenitic stainless steel construction is specified.

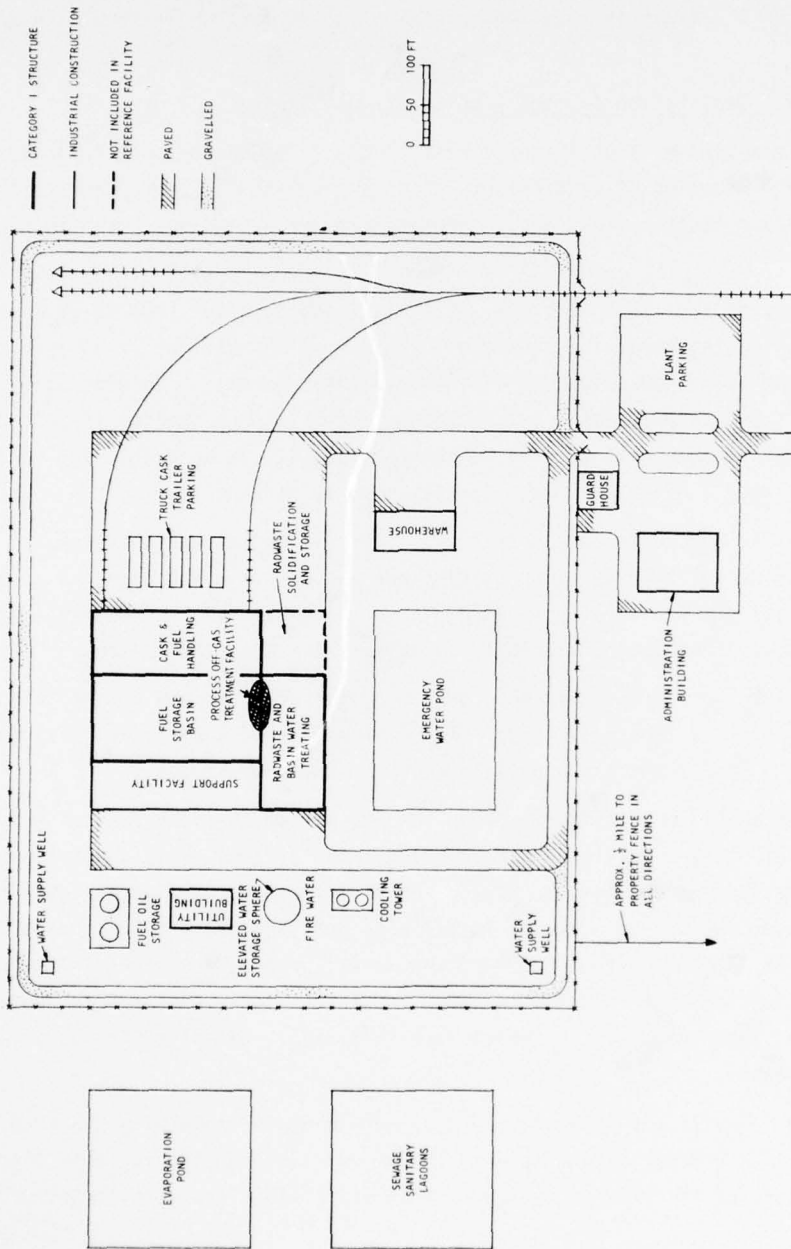


FIGURE 4.10.10. Approximate Location of Facilities for Process Off-gas Treatment Within the Independent Spent Fuel Storage Basin

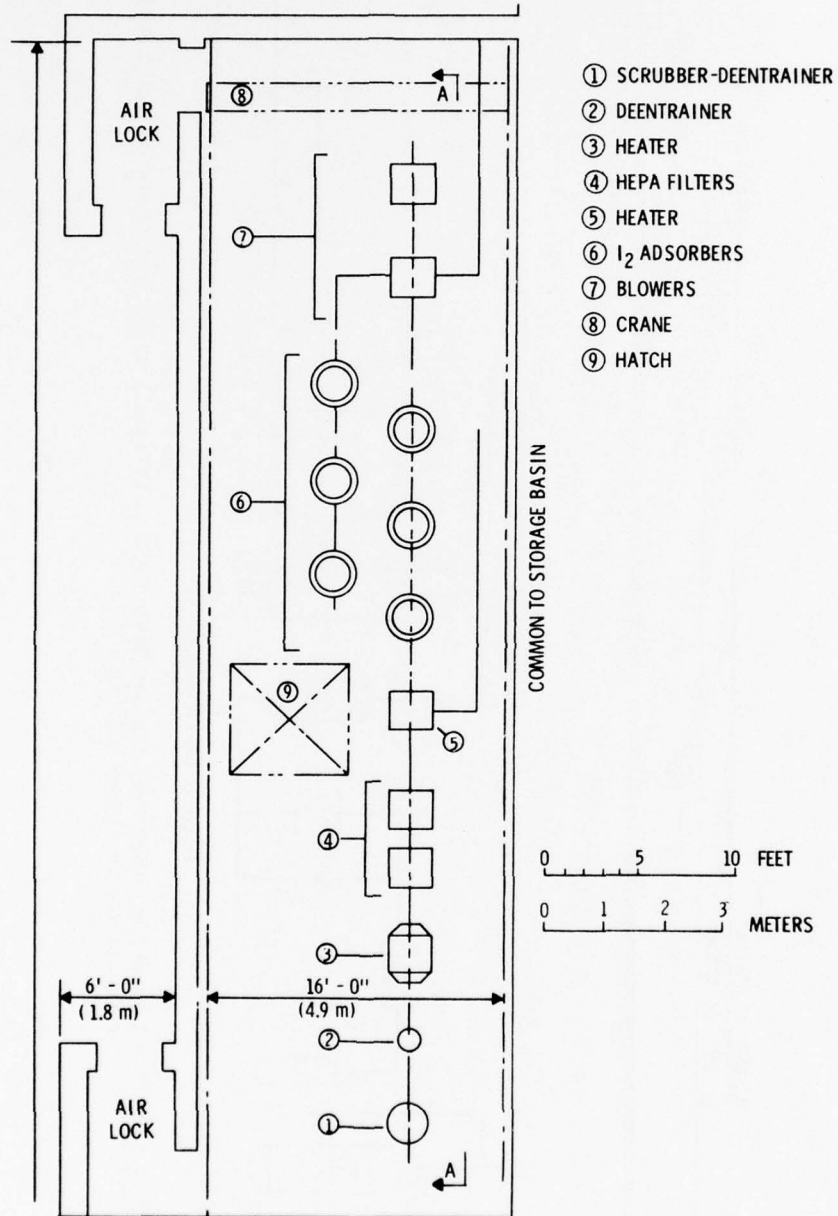


FIGURE 4.10.11. Independent Spent Fuel Storage Basin Process Off-gas System, General Plan

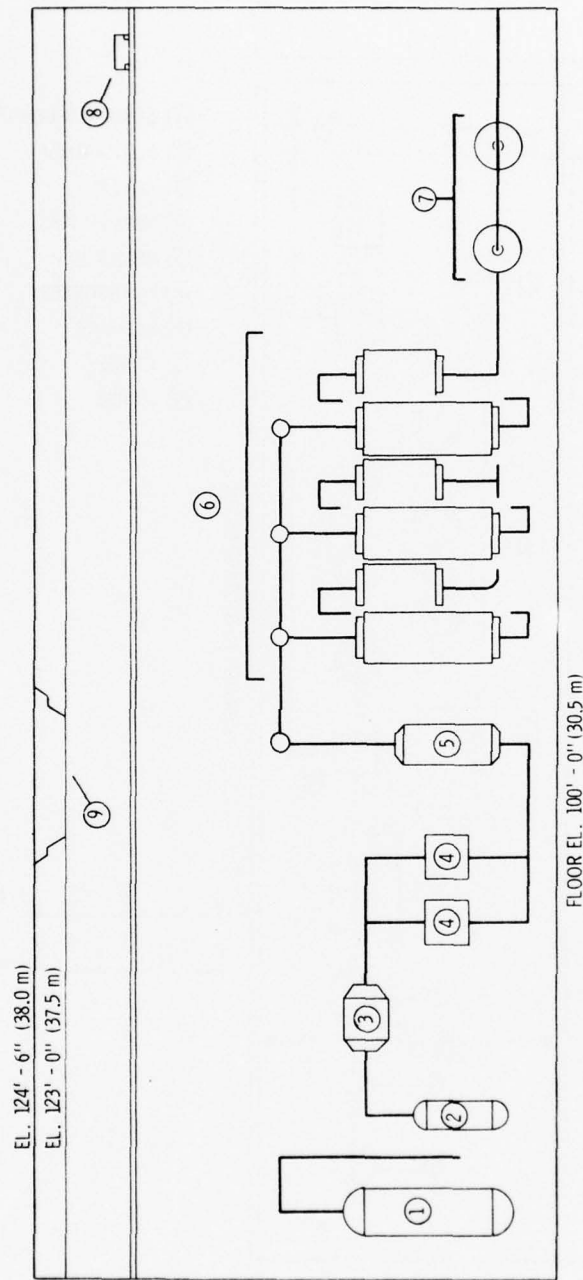


FIGURE 4.10.12. Independent Spent Fuel Storage Basin Process Off-gas System, Section A-A (Circled numbers refer to key in Figure 4.10.11.)

HEPA Filter. The HEPA filter is a standard one of metal-asbestos construction. Details concerning HEPA filters are presented in Section 4.8. Two filters are installed parallel-wise to allow continuous operation. Based on the gas flow of $7.9 \text{ m}^3/\text{min}$ at 45°C , two small HEPA filters are adequate (maximum capacity $4.3 \text{ m}^3/\text{min}$). The face of each filter is $0.3 \times 0.3 \text{ m}$ and 0.15 m thick. A DF of 10^3 for particles is obtained with this filter. Both HEPA filters are instrumented with pressure differential and activity monitors.

Iodine Adsorber Preheater. The iodine adsorber preheater uses electrical heaters to raise the gas temperature to 150°C . A nominal heat load of 16 kW is required, and a design heater installation of 25 kW is recommended. The heater power is automatically controlled. Austenitic stainless steel construction is specified.

Iodine Adsorbers. Figure 4.10.13 is a schematic of the iodine adsorber used in the ISFSB process off-gas system. The adsorbent, either silver-zeolite or silicate, is encapsulated in separate filter cartridges so that each cartridge can be readily inserted or removed from the filter train when instrumentation indicates that iodine breakthrough has occurred. Figure 4.10.13 shows a detail of a cartridge. The filter cartridges have locking grooves for ready loading and unloading of the adsorbent train vessels. Each cartridge weighs about 125 kg (275 lb) and is dimensioned to fit into standard 55-gal drums for storage or disposal.

Additional information concerning the iodine adsorbent portion of the process off-gas system includes the following:

- The halogen inventory in the independent spent fuel storage basin off-gas is about 4.7 g/year .
- The adsorbent train is the only iodine recovery mechanism.
- The silver-zeolite contains 12% silver by weight and has a dry density of 0.68 g/cm^3 .
- An 80% bed loading is used to give an average loading of $0.08 \text{ grams of iodine/cm}^3$.
- The adsorbent train provides an iodine DF of 10^3 .
- The two-cartridge iodine adsorbent train and backup cartridge ($0.18 \text{ m}^3/\text{cartridge}$) are changed only when breakthrough is detected between the working bed and the back-up cartridge.
- The capacity of each cartridge is $13,000 \text{ g}$ of iodine, and cartridges are expected to last the life of the ISFSB.
- Three sets of adsorber trains are used.
- The volumetric flow rate at the iodine adsorbent vessel inlet is $10.5 \text{ m}^3/\text{min}$ ($371 \text{ ft}^3/\text{min}$) given an operating temperature of 150°C .
- The inlet pressure is 1 atm (14.7 psi).
- The pressure drop across the three cartridge trains is approximately 0.17 atm (2.5 psi).
- The beds are designed for a superficial flow velocity of about 15 m/min (50 ft/min).

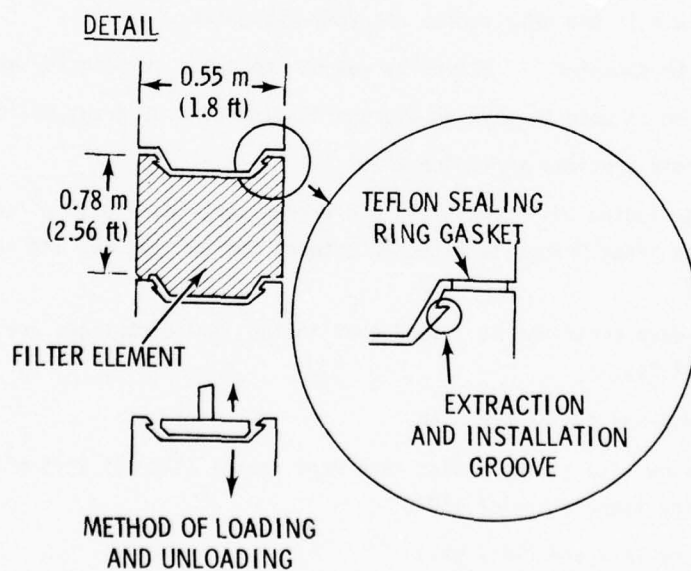
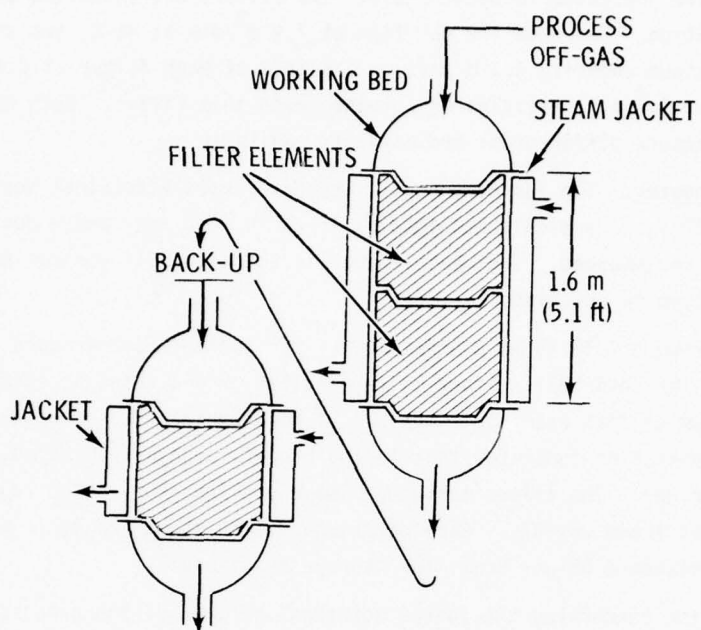


FIGURE 4.10.13. Iodine Adsorber and Cartridge Detail

Iodine-129 samplers are positioned before and after the primary and back-up iodine adsorbers. The sampling systems involve small heated beds of silver-zeolite positioned on top of lithium-drifted germanium detectors; these detectors measure the 30 keV x-ray from iodine-129. A fraction of the off-gas stream is drawn continuously through the beds; however, the samplers must be evacuated to remove krypton-85 prior to measurement. A multichannel analyzer with sequential switching is used to monitor a given sampler at a desired frequency.

Shielding and Remote Handling Equipment. All normal process operations are handled in a contact-maintained cell, and external dose rates are limited to less than 1 mrem/hr. As indicated earlier, shielded labyrinth entries to the process area are used for personnel access. In such cases, however, exposure is rigorously controlled. The iodine adsorbent is contained in cartridges that can be readily handled, using a special grapple in combination with an overhead crane.

4.10.2.5 Process Off-gas System Operating and Maintenance Requirements

The facility operates as part of the ISFSB 24 hours a day, 7 days a week, 365 days a year. Normal activities include monitoring of the iodine adsorber systems and normal maintenance and replacement. The iodine beds are operated until iodine is detected on the exit side of the cartridge. At this breakthrough, the radiation monitors alarm and the gas flow is switched to the parallel system and the loaded adsorbents replaced with fresh adsorbent. The HEPA filters are also changed periodically, about every 12 months, as the radioactivity builds up.

Staffing. Estimated staffing requirements for the POG system are shown in Table 4.10.17.

TABLE 4.10.17. Staffing Requirements for the Independent Fuel Storage Basin Process Off-gas System

<u>Job Description</u>	<u>Personnel Required, man-yr/yr</u>
Operators	1
Radiation monitors	0.5
Maintenance craftsmen	1

Supplies and Utilities. The only supplies indicated for the reference process off-gas system are HEPA filters. Table 4.10.18 gives estimates of utility requirements.

4.10.2.6 Process Off-gas System Secondary Radioactive Wastes

Estimates of secondary radioactive wastes associated with the reference facility are shown in Table 4.10.19.

4.10.2.7 Process Off-gas System Emissions

Facility emissions are characterized in Table 4.10.20.

TABLE 4.10.18. Utility Requirements for the Independent Spent Fuel Storage Basin Process Off-gas System

Utility	Use Rate	Annual Requirement
Electricity	25 kW	1.8×10^5 kWh
Steam	50 kg/hr	3.6×10^5 kg

TABLE 4.10.19. Independent Spent Fuel Storage Basin Process Off-gas System Secondary Radioactive Wastes

Description	Volume, m ³ /yr	Radioactivity Factor ^(a)
Combustible and compactable waste	30	1×10^{-5}

a. Fraction of input activity (Table 4.10.14 excluding volatiles) in secondary wastes.

TABLE 4.10.20. Emissions from the Independent Spent Fuel Storage Basin Process Off-gas System

Emission	Description	Annual Quantity	Radioactivity Release Factor to Atmosphere ^(a)
Gaseous	Process off-gas	Air 3.9×10^6 m ³	³ H 1.0 ¹⁴ C 1.0 ⁸⁵ Kr 1.0 ¹²⁹ I 1×10^{-3}
	Minor accident integrated annual release		Included in operational release

a. Fraction of input activity (Table 4.10.14) released to atmosphere over a period of 365 days/yr.

4.10.2.8 Process Off-gas System Decommissioning Considerations

The ISFSB process off-gas facility is designed to be functional for the life of the plant. The cell structure is provided with a stainless steel floor pan, a sump and protective coatings to facilitate decontamination. The ability to remove the silver-zeolite and the filters will aid in final decontamination. It is expected that at the end of the ISFSB facilities' operating life, the process off-gas facility will be relatively free of contamination.

4.10.2.9 Process Off-gas System Postulated Accidents

The two postulated minor accidents for the ISFSB process off-gas system (Table 4.10.21) are identical to Accidents 4.9.1 and 4.9.2 presented in Table 4.9.9 of the section on FRP dissolver off-gas iodine recovery. These accidents involve a plugged iodine bed and a torn HEPA filter,

respectively. One of the moderate accidents postulated for the ISFSB POG system is the same as Accident 4.9.4 in Table 4.9.10. Table 4.10.22 details the other moderate accidents posed for the reference facility. No accidents that could be classified as severe accidents could be realistically postulated for this technology.

TABLE 4.10.21. Minor Accidents of the Independent Spent Fuel Storage Basin Process Off-gas Facility

<u>Accident No. and Description</u>	<u>Sequence of Events</u>	<u>Safety Systems</u>	<u>Release</u>
4.10.4 - Plugged iodine bed.	See Table 4.9.9 in Section 4.9.1		
4.10.5 - Torn HEPA filter.			

TABLE 4.10.22. Moderate Accidents of the Independent Spent Fuel Storage Process Off-gas Facility

<u>Accident No. and Description</u>	<u>Sequence of Events</u>	<u>Safety Systems</u>	<u>Release</u>
4.10.6 - Process off-gas system shutdown.	1. Iodine system fails.	1. Radiation and air-flow monitoring provides continuous information.	If the process off-gas is vented to the stack, which has a gas flow of 4×10^5 m ³ /hr, the iodine release concentration would be 2.5×10^{-10} μ Ci/cm ³ . This is below the maximum permissible concentration for soluble and insoluble species in air.
	2. Parallel system not in service.	2. Receipt of additional fuel for storage would be limited until repairs are completed.	
	3. Radiation and air-flow monitors detect venting to ISFSB stack.	3. The process off-gas could be sent to the emergency APS or sent directly to ISFSB stack.	
	4. ISFSB continues to operate.		
4.10.7 - Iodine canister adsorbent spill during replacement.	See Table 4.9.10 in Section 4.9.1.	None	

4.10.2.10 Facility Costs for the Process Off-gas System

Estimates have been made, in mid-1976 dollars, of incremental capital, operating, and levelized unit costs. A complete description of the cost estimate bases, assumptions, and definitions is given in Section 3.8.

Capital Costs. The capital cost estimate for the process off-gas system is shown in Table 4.10.23. Because fuel shipping casks cannot be unloaded without controlled venting, it is assumed that the reference facility will be constructed concurrently with the ISFSB.

The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation. The estimate covers all capital costs specifically resulting from the inclusion of the POG facility as an integral part of the ISFSB. The costs include the close-capture ventilation collectors in the storage basin, which collect off-gas

TABLE 4.10.23. Capital Cost Estimate for the Independent Spent Fuel Storage Basin Process Off-gas System

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		3	330	45	375
Buildings and structures		43	175	505	680
Bulk materials		25	400	310	710
Site improvements		--	--	--	--
Subtotal of direct site construction costs		71	905	860	1,765
Indirect site construction costs	20	14	310	420	730
Total field cost	20	85	1,215	1,280	2,495
Architect-engineer services					495
Subtotal					2,990
Owner's cost					910
Total facility cost					3,900
Estimate accuracy range					±25%

from leaking stored fuel canisters, and the cask venting collection headers. Costs also include the effect of incremental additions for ISFSB utilities supplied to the reference system, including electricity, compressed air, steam, water and space ventilation. General ISFSB costs for such services as laboratories, warehouses, and administration offices are not allocated to the POG system.

Operating Costs. Direct labor costs are derived from the manpower requirements shown in Table 4.10.17. The cost of silver-zeolite, estimated at \$110/kg, is a one-time requirement in the beginning year of facility operation. Annual maintenance materials costs are estimated at 3% of major equipment costs. Table 4.10.24 shows the operating cost components.

Levelized Unit Costs. The levelized unit cost, including the levelized capital and operating charges, is shown in Table 4.10.25. The unit cost calculation assumes private ownership of the facilities and a 15-year economic life.

4.10.2.11 Construction Requirements for the Independent Spent Fuel Storage Basin Process Off-gas System

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating the impact of construction activities.

TABLE 4.10.24. Independent Spent Fuel Storage Basin
Process Off-gas System Operating
Cost Estimate

Cost Element	Annual Costs, \$1000s	
	First Year	Subsequent Years
Direct labor	20	20
Process materials (silver-zeolite)	160	0
Utilities	3	3
Maintenance materials	10	10
Overhead	30	30
Miscellaneous	12	12
Total	235 $\begin{smallmatrix} +50\% \\ -25\% \end{smallmatrix}$	75 $\begin{smallmatrix} +50\% \\ -25\% \end{smallmatrix}$

TABLE 4.10.25. Independent Spent Fuel Storage Basin
Process Off-gas System Levelized Unit
Cost Estimate

Cost Element	Unit Cost, \$/kg HM
Levelized capital charge	1.80
Levelized operating charge	0.20
Levelized total unit cost	2.00 $\pm 35\%$

Project Schedules and Construction Manpower. The schedule for engineering, procurement and construction of the facility is an integral factor in the overall schedule for the ISFSB. The field labor force estimated for the construction of the process off-gas facility is tabulated below:

	Man-hours, 1000s
Manual field labor	85
Nonmanual field labor	20
Total field labor	105

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials and services provided at the site of the ISFSB while offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is shown below:

	Costs, \$1,000s
Onsite	1,500
Offsite	2,400
Total	3,900

Site Requirements. The facility will share the same site as the ISFSB. No additional site requirements beyond those for the ISFSB are identifiable. Land commitments for the facility are included with those of the ISFSB.

Water. Water to be used during the construction period is estimated at 1100 m^3 ($0.3 \times 10^6 \text{ gal}$)

Construction Materials. Materials committed to facility construction are:

Concrete	380 m^3	(500 yd^3)
Steel	80 MT	(90 tons)
Copper	0.4 MT	(0.5 tons)
Lumber	15 m^3	(6 MFBM)

Energy. Energy resources used during construction will be:

Propane	11 m^3	(3,000 gal)
Diesel	114 m^3	(30,000 gal)
Gasoline	76 m^3	(20,000 gal)
Electricity		
Peak Demand	125 kW	
Total consumption	60,000 kWh	

Transportation Requirements. No transportation requirements for the process off-gas system have been identified beyond those for the ISFSB.

4.10.2.12 Effects of Fuel Cycle Options

The reference process for the independent spent fuel storage basin process off-gas system assumes reprocessing of LWR fuel and recycling the retrieved uranium and plutonium. The following alternative fuel cycle modes have also been assessed insofar as they relate to off-gas treatment at the storage basin.

No Recycle. Eliminating the fuel reprocessing operation does not eliminate the generation of off-gas from the fuel elements being received for storage and control of radioactive materials being released both from intact and failed fuel. A process off-gas system would still be required.

Uranium Recycle Only, with Plutonium to a Repository. This alternative is expected to generate the same amount of process off-gas as in the uranium and plutonium recycle case.

Uranium Recycle Only, with Plutonium to HLW. This alternative would generate the same quantity of process off-gas as in the uranium and plutonium recycle case.

4.10.3 Safeguards and Physical Protection Requirements for Process Off-gas Treatment

The safeguards and physical protection requirements for these facilities, processes and recovered products are less stringent than those for dissolver off-gas treatment described in Section 4.9.5. The only gaseous radionuclide recovered in the process off-gas systems is iodine-129, and the amount in these systems will be at most a few percent of that in the dissolver off-gas system.

REFERENCES FOR SECTION 4.10

1. Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle, Vol 2. ERDA 76-43, Energy Research and Development Administration, Washington, DC. May 1976.
2. J. G. Wilhelm and J. Furrer, "Head End Iodine Removal from a Reprocessing Plant with a Solid Sorbent," presented at the Fourteenth ERDA Air Cleaning Conference, Sun Valley, Idaho, August 2-4, 1976.
3. D. T. Pence and T. R. Thomas, "NO_x Abatement at Nuclear Processing Plants," Proceedings of the Second AEC Environmental Protection Conference, WASH-1132[74], July 1974.
4. Nuclear Fuel Recovery and Recycling Center: Preliminary Safety Analysis Report. Docket 50-564, Exxon Nuclear Company, Richland, WA, 1976.

4.11 FUEL REPROCESSING PLANT ATMOSPHERIC PROTECTION SYSTEM

4.11 FRP ATMOSPHERIC PROTECTION SYSTEM

The atmospheric protection system (APS) as applied to the fuel reprocessing plant (FRP) is the final stage of filtration for building ventilation air and process off-gas. Figure 4.11.1 shows the location of the facilities housing this system within the FRP. Table 4.11.1 summarizes the annual quantities of radioactive materials associated with the various off-gas streams flowing into the APS, assuming prior treatments of the dissolver off-gas and vessel off-gas streams as described in Sections 4.9 and 4.10.

Figure 4.11.2 is a process flow diagram for the FRP APS. All off-gas streams except the general building ventilation air are treated before entering the APS. The APS consists of a prefilter followed by high-efficiency particulate air (HEPA) filters grouped into modules mounted in a concrete, below-ground-level structure. The prefilter can be of several different media and configurations. The APS uses exhaust fans to develop the subatmospheric pressure needed to move the large volume of air. Motors, blowers, mounts, ducts and breeching are provided to exhaust the filtered air to the exhaust stack.

The three alternative atmospheric protection systems considered in the following sections differ only in the type of prefilter used. Table 4.11.2 compares these three alternatives, providing data concerning the various prefilters as well as the standard HEPA filters used in all three systems.

4.11.1 Group III Filter Module/HEPA Filter Atmospheric Protection System

The combination of a Group III filter module followed by a HEPA filter installation has been applied frequently for radioactive particle removal. The Group III filter module comprises several Group III glass fiber filter units mounted together. The group number indicates the filter's efficiency, with III as the highest. Section 4.8 discusses the Group III filter in detail, providing a description and illustrations. The module size of the prefilter will depend upon the manufacturer's design; but, generally, the module dimensions are compatible with the basic dimension of the HEPA filter with which it is used.

4.11.1.1 Alternative Prefilters for the Group III Filter Module

Several types of modular Group III prefilters are commercially available and could be selected for use in the reference APS. Alternative Group I and II prefilters (panel-type) are of light construction and difficult to seal properly. These prefilters also have limited efficiency and would be marginal for this application. The Group III filter chosen for the reference APS is the extended-medium, dry-type, throw-away filter. Replaceable-medium prefilters were not selected because of problems with contamination control when the media are changed, the unjustified expense of changing the highly-contaminated media, and the greater initial cost.

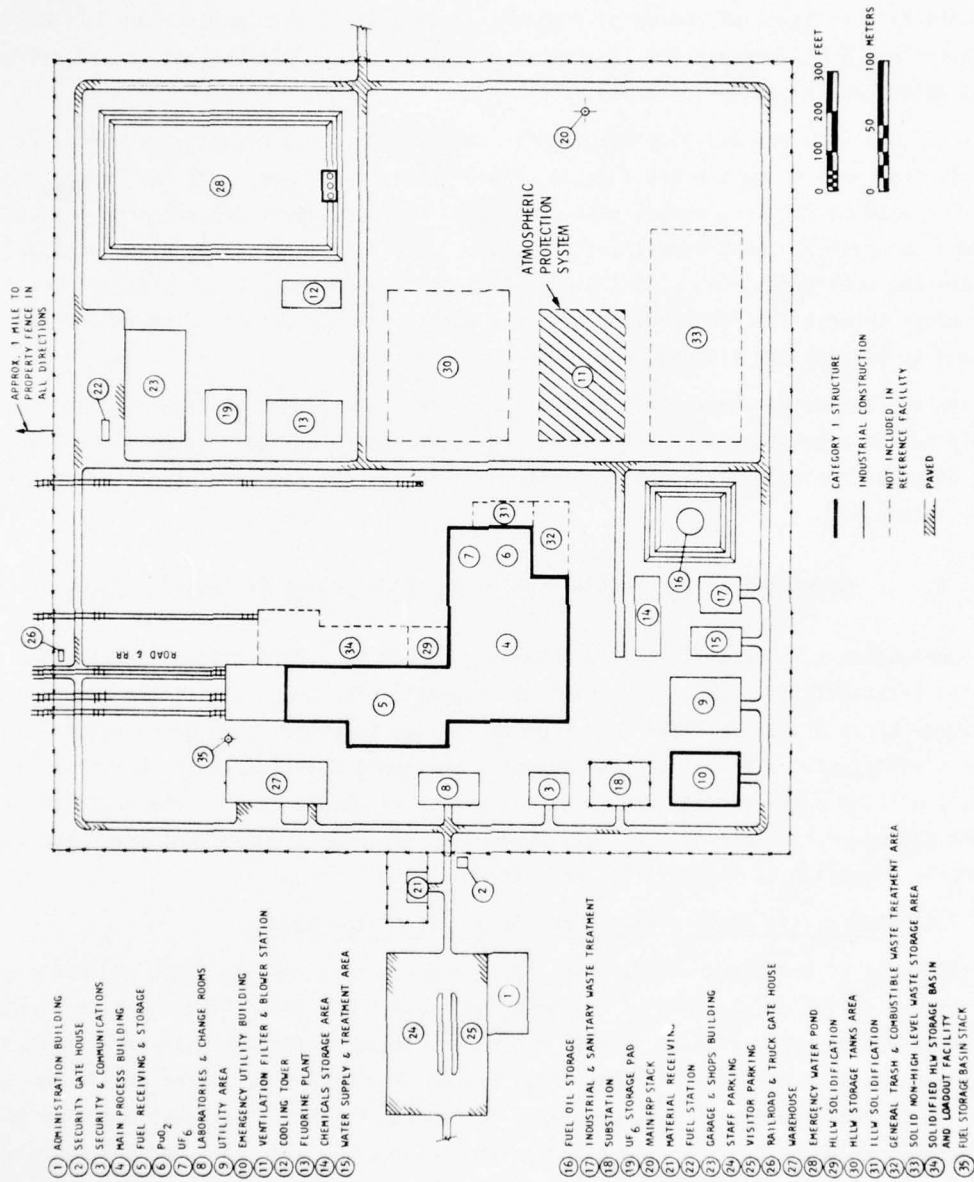


FIGURE 4.11.1. Approximate Location of the Atmospheric Protection System Within the Reference Fuel Reprocessing Plant

TABLE 4.11.1. Fuel Reprocessing Plant Atmospheric Protection System Feed Activity

Description	Activation Products	Activity, Ci/yr	
		Fission Products	Actinides
Dissolver off-gas after combined treatment ^(a)	^{14}C 1.1×10^1	^3H (b)	^{239}Pu 7.2×10^{-7}
		^{129}I 6.9×10^{-2}	^{241}Pu 3.5×10^{-4}
		^{85}Kr 1.68×10^6	Other Pu 1.2×10^{-5}
		$^{90}\text{Sr} + ^{90}\text{Y}$ 2.4×10^{-4}	$^{242}\text{Cm} + ^{244}\text{Cm}$ 3.4×10^{-5}
		$^{95}\text{Zr} + ^{95}\text{Nb}$ 2.2×10^{-5}	All others 1.8×10^{-6}
		$^{106}\text{Ru} + ^{106}\text{Rh}$ 7.5	Total 4.0×10^{-4}
		$^{134}\text{Cs} + ^{137}\text{Cs}$	
		+ ^{137m}Ba 6.0×10^{-4}	
		$^{144}\text{Ce} + ^{144}\text{Pr}$ 9.6×10^{-4}	
		All others 2.0×10^{-4}	
		Total 1.7×10^6	
Vessel off-gas after treatment ^(c)		^3H (b)	^{239}Pu 7.2×10^{-5}
		^{129}I 3.5×10^{-4}	^{241}Pu 3.5×10^{-2}
		^{85}Kr 1.7×10^1	Other Pu 1.2×10^{-3}
		$^{90}\text{Sr} + ^{90}\text{Y}$ 2.4×10^{-2}	$^{242}\text{Cm} + ^{244}\text{Cm}$ 3.4×10^{-3}
		$^{95}\text{Zr} + ^{95}\text{Nb}$ 2.2×10^{-3}	All others 1.8×10^{-4}
		$^{106}\text{Ru} + ^{106}\text{Rh}$ 3.8	Total 4.0×10^{-2}
		$^{134}\text{Cs} + ^{137}\text{Cs}$	
		+ ^{137m}Ba 6.0×10^{-2}	
		$^{144}\text{Ce} + ^{144}\text{Pr}$ 9.6×10^{-2}	
		All others 2.0×10^{-2}	
		Total 2.1×10^1	
HVAC stream ^(d)		^3H 8.4×10^{-6}	^{239}Pu 7.2×10^{-6}
		^{129}I 7.0×10^{-10}	^{241}Pu 3.5×10^{-3}
		^{85}Kr 1.7×10^{-4}	Other Pu 1.2×10^{-4}
		$^{90}\text{Sr} + ^{90}\text{Y}$ 2.4×10^{-3}	$^{242}\text{Cm} + ^{244}\text{Cm}$ 3.4×10^{-4}
		$^{95}\text{Zr} + ^{95}\text{Nb}$ 2.2×10^{-4}	All others 1.8×10^{-5}
		$^{106}\text{Ru} + ^{106}\text{Rh}$ 7.6×10^{-3}	Total 4.0×10^{-3}
		$^{134}\text{Cs} + ^{137}\text{Cs}$	
		+ ^{137m}Ba 6.0×10^{-3}	
		$^{144}\text{Ce} + ^{144}\text{Pr}$ 9.6×10^{-3}	
		All others 2.0×10^{-3}	
		Total 2.8×10^{-2}	
Composite ^(e) (DOG + VOG + HVAC)	^{14}C 1.1×10^1	^3H (b)	^{239}Pu 8.0×10^{-5}
		^{129}I 6.9×10^{-2}	^{241}Pu 3.9×10^{-2}
		^{85}Kr 1.68×10^6	Other Pu 1.3×10^{-3}
		$^{90}\text{Sr} + ^{90}\text{Y}$ 2.7×10^{-2}	$^{242}\text{Cm} + ^{244}\text{Cm}$ 3.8×10^{-3}
		$^{95}\text{Zr} + ^{95}\text{Nb}$ 2.4×10^{-3}	All others 2.0×10^{-4}
		$^{106}\text{Ru} + ^{106}\text{Rh}$ 1.1×10^1 ^(f)	Total 4.4×10^{-2}
		$^{134}\text{Cs} + ^{137}\text{Cs}$	
		+ ^{137m}Ba 6.7×10^{-2}	
		$^{144}\text{Ce} + ^{144}\text{Pr}$ 1.1×10^{-1}	
		All others 2.2×10^{-2}	
		Total 1.7×10^6	

a. Based on Tables 4.9.1 and 4.9.47 without the APS contributions to the release factor. Volume = $1.2 \times 10^6 \text{ m}^3/\text{yr}$.

b. Removed during treatment and ultimately released via the excess water vaporizer.

c. Based on Tables 4.10.1 and 4.10.8 without the APS contributions to the release factor. Volume = $7.3 \times 10^7 \text{ m}^3/\text{yr}$.

d. Based on waste characterization Table 3.3.27. Volume = $3.6 \times 10^9 \text{ m}^3/\text{yr}$.

e. Volume = $3.7 \times 10^9 \text{ m}^3/\text{yr}$.

f. Approximately 90% volatile and 10% particulate.

4.11.1.2 Design Basis for the Group III Filter Module/HEPA Filter Atmospheric Protection System

Certain features of the FRP ventilation system and process off-gas treatment systems are relevant to the design features of the APS:

- Scrubbers, absorption beds, and filters are installed near prominent sources of airborne particles and gases. These lower the possibility of corrosive gases and hazardous fumes and vapors.
- Air supply systems have a roughing filter with a 90% dust spot efficiency. This reduces dust load in the system and increases the life of the filters in the APS.

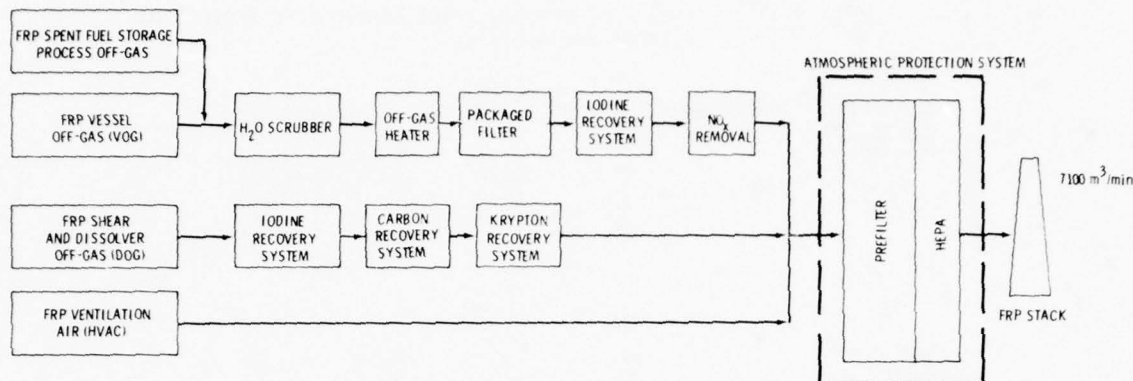


FIGURE 4.11.2. Fuel Reprocessing Plant Atmospheric Protection System Process Flow Diagram

- Air supply fans are turned off at the loss of exhaust below a predetermined pressure drop in the building or other critical areas, such as process cells.
- Rate-of-rise temperature sensors that indicate and alarm at local and central control panels will be installed upstream of the APS.

The reference FRP APS incorporates the following features:

- The APS filter banks are made of parallel units. No single unit shall carry more than one-half the total design flow. Each unit has sufficient reserve capacity to maintain a safe exhaust flow through the system in the event of shutdown of a single unit.
- The prefilter has a minimum particle removal efficiency of 90%. The HEPA filter installation has a minimum particle removal efficiency of 99.9%.
- Provision is made for sensing and recording pressure drop across the prefilter and across the HEPA filter. The pressure signal will activate an alarm when pressure drop is too low or too high.
- Provision is made for measuring radiation levels near the face of the prefilter and final filter (HEPA).
- Ports are provided for measuring the efficiency of the prefilter and the HEPA filter during operation at 6-month intervals.
- Samplers are incorporated into the design to permit measurement of concentration of airborne radioactive material at a point upstream of the prefilter, downstream of the prefilter bank, and downstream of the HEPA filter bank.
- Stainless steel screens are an integral part of the prefilter and HEPA filter module on the downstream side to prevent pieces of the media from entering the ventilation system.

4.11.1.3 Process for the Group III Filter Module/HEPA Filter Atmospheric Protective System

The Group III filter module/HEPA filter APS process is essentially the same as that depicted in Figure 4.11.2. The function of the Group III prefilter, as the name implies, is to

TABLE 4.11.2. Three Alternative Atmospheric Protection Systems for the Reference Fuel Reprocessing Plant

Filter or Alternative System	Pressure Drop, cm of H ₂ O	Size, m	Number of Units	Bed Area, m ²	Face Velocity, m/Min	Efficiency, %	DF(a)	Is Filter or System Removable?	Replacement Cycle, yr
HEPA filter (used in all three alternative systems)	2.5	0.61 x 0.61 x 0.3	240	90	1.5	99.9	10 ³	Yes	3
Group III filter module (prefilter)	0.8	0.61 x 0.61 x 0.3	240	(c)	(c)	90	10	Yes	1
• Alternative APS: Group III filter module/HEPA filter	3.3	(c)	(c)	(c)	(c)	99.99	10 ⁴	Yes	(c)
Sand filter (prefilter)	18-25	68.5 x 68.5	1	4700	1.5	90	10	No	20
• Alternative APS: sand filter/HEPA filter	20-28	(c)	(c)	(c)	(c)	99.99	10 ⁴	No	(c)
Deep-bed glass fiber filter (prefilter)	10	27.4 x 27.4	1	750	15	90	10	No	15-20
• Alternative APS: deep-bed glass fiber filter/HEPA filter	13	(c)	(c)	(c)	(c)	99.99	10 ⁴	No	(c)

a. Decontamination factor.

b. Approach velocity of air through medium is 1.5 m/min (5 fpm); face velocity of filter unit is 750 m/min (250 fpm).

c. Not applicable.

remove a substantial fraction of the larger particles from the air stream and to lengthen the life of the HEPA filters. Exhaust air under slightly negative pressure enters the filtration bank made up of multiple Group III filter module followed by the HEPA bank. Air moves horizontally through the filter bank under the influence of fans at the exhaust.

4.11.1.4 Facility Description for the Group III Filter Module/HEPA Filter Atmospheric Protection System

Figure 4.11.3 shows the arrangement of the reference facility. The APS is housed in a concrete structure 26.2 m (86 ft) long and 25.3 m (83 ft) wide. The attached exhaust blower station is 27.4 m (90 ft) long and 25.3 m (83 ft) wide. The overall height of the building is 6.97 m (23 ft), with the lower 3 m (10 ft) below grade. It is divided equally into 8 side-by-side compartments: within each compartment a prefilter and a HEPA filter mounting frame are installed in series. Each mounting frame is seal-welded to the compartment wall and holds an array 3 filters high and 10 filters wide. In the 8 compartments are 240 prefilters, and behind them a like number of HEPA filters.

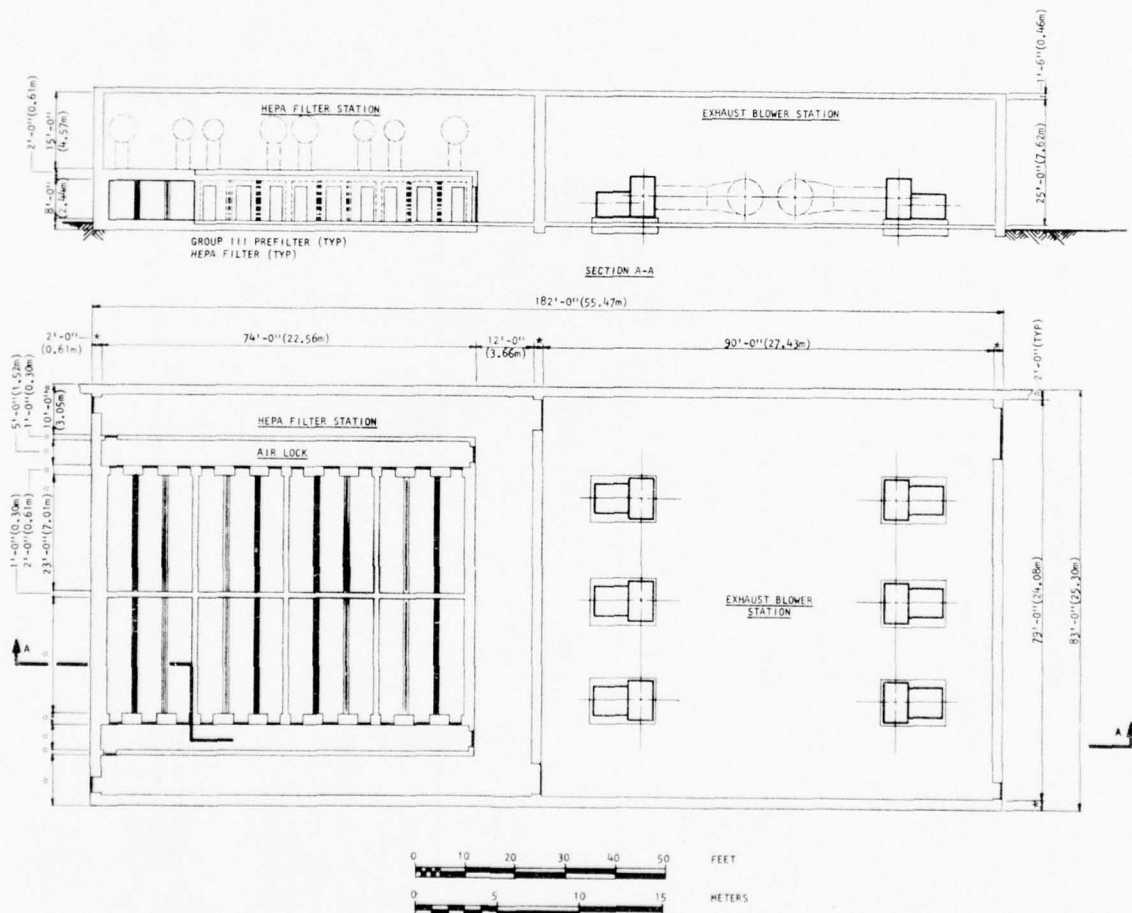


FIGURE 4.11.3. Group III Filter Module/HEPA Filter Atmospheric Protection System, General Plan and Section A-A

4.11.7

Access to the filter compartments is through an air lock system. These access passageways are essential in construction and testing and will provide the access during filter replacement. The design is such that change of filters can be performed with difficulty commensurate with the radiation level on the filters. This radiation build-up must be monitored to provide information for scheduling filter replacement.

Air distribution ducts are routed to the top of the room. Air enters from the top on one side of the room, passes through the filter banks, and travels to the suction side of the exhaust blower. Stainless steel pans and sumps are provided to collect any contaminated fluids for disposal through the liquid radioactive waste system.

The APS facility is constructed of reinforced concrete to assure that the structure will withstand design-basis natural phenomena, including earthquakes and tornadoes, and will prevent penetration by a maximum credible fire and/or explosion. The facility is designed to meet Category I structural requirements.

Monitoring System. Beta and gamma radiation detectors are mounted within the housing near the filters to continuously monitor activity levels. Pressure differential monitors and alarms check the performance of the filter banks and indicate abnormal occurrences as well as the need for filter changes.

Fire Protection System. Exhaust air ducts to the filter room are equipped with debris screens to intercept airborne burning debris before it can enter the air plenum. Detection is provided by a smoke detector and a combination rate-of-rise and fixed-temperature detector. Suppression is accomplished by spraying water as a fine mist on the debris screens. Both detectors must be in an alarm condition simultaneously to actuate the water supply.

Air Moving Equipment. Five exhaust blowers supply the motive force to draw air through the FRP building ventilation system to the APS. Another identical unit of blowers is in a standby mode during normal operation. The exhaust blowers are centrifugal-type blowers, rated at $1415 \text{ m}^3/\text{min}$ (50,000 cfm) at 115 cm (45 in.) of water differential pressure each. Each blower is driven by a 375-kW electric motor.

Shielding and Remote Handling Equipment. The replacement of prefilters and HEPA filters requires that temporary local shielding panels be moved into place to protect the workers from radiation during the change. The extent of shielding and the complexity of remote handling equipment is determined by the rate of build-up of radioactive material on the filters and by the length of operation prior to filter change. The removed filters are placed in shielded containers for transport to solid radioactive waste storage and eventual disposal.

4.11.1.5 Operating and Maintenance Requirements for the Group III Filter Module/HEPA Filter Atmospheric Protection System

The facility operates 24 hr/day, 7 days/wk, the year round. Normal activities include monitoring pressure drop across filters, sampling, and normal maintenance and replacement activities. All normal process operations, filter removal, and filter installation are handled manually. HEPA filters and prefilters will be replaced as required to maintain pressure and to comply with prescribed radiation limits. The APS is designed so that about two-thirds of the prefilters and HEPA filters can continue to be used while the remaining filters

4.11.8

are changed. It is expected that all of the prefilters and one-third of the HEPA filters will be replaced each year. These filters are treated as FRP compactable waste. Prior to use, a new filter section will be tested using dioctylphthalate (DOP) aerosols. Detailed instructions for installation and testing are available.⁽¹⁾

Staffing. Estimated staffing requirements for operating the reference system are shown in Table 4.11.3.

TABLE 4.11.3. Staffing Requirements for the Group III Filter Module/HEPA Filter Atmospheric Protection System

<u>Job Description</u>	<u>Personnel Required, man-yr/yr</u>
Operators	1.5
Radiation monitors	0.25
Maintenance craftsmen	0.5

Supplies and Utilities. Table 4.11.4 shows the supplies and utilities used in the reference APS operations.

TABLE 4.11.4. Supply Requirements for the Group III Filter Module/HEPA Filter Atmospheric Protection System

<u>Supply</u>	<u>Annual Requirements</u>	<u>Use Rate</u>
Electricity	1.6×10^7 kWh	1875 KW
Prefilters	240	
HEPA filters	80	
Detergent (for decontamination and cleaning)	300 kg	

4.11.1.6 Secondary Radioactive Wastes for the Group III Filter Module/HEPA Filter Atmospheric Protection System

Estimates of secondary radioactive wastes associated with the reference system are shown in Table 4.11.5.

TABLE 4.11.5. Secondary Radioactive Wastes from the Group III Filter Module/HEPA Filter Atmospheric Protection System

<u>Description</u>	<u>Volume, m³/yr</u>	<u>Radioactivity Factor^(a)</u>
Combustible and compactable waste	80	1×10^{-5}
Failed equipment	80	1×10^{-5}

a. Fraction of input activity (Table 4.11.1, excluding volatiles) in secondary wastes.

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4.11.1.7 Emissions from the Group III Filter Module/HEPA Filter Atmospheric Protection System

Facility emissions are characterized in Table 4.11.6.

TABLE 4.11.6. Emissions from the Group III Filter Module/HEPA Filter Atmospheric Protection System

<u>Emission</u>	<u>Description</u>	<u>Annual Quantity</u>	<u>Radioactivity Release Factor(a)</u>
Gaseous	Composite	Air 3.7 x 10 ⁹ m ³	³ H 1.0
			⁸⁵ Kr 1.0
			¹²⁹ I 1.0
			¹⁰⁶ Ru-Rh 0.9 ^(b)
			All others 1 x 10 ⁻⁴
	Minor accident integrated annual release		None identified

- a. Fraction of input activity (Table 4.11.1) released to atmosphere. Released over 365 days/yr. Peak release rates of volatiles may be approximated by assuming release over 30 days/yr.
- b. Assumes that volatile ruthenium is not converted to particulate ruthenium before it reaches the APS.

4.11.1.8 Decommissioning Considerations for the Group III Filter Module/HEPA Filter Atmospheric Protection System

The facility that houses the reference APS is assumed to have an operational life of 30 yr. It is projected that at the end of its operating life, the facility will be relatively free of contamination except for the Group III filter modules and HEPA filters. Ease of retirement and removal will be an important consideration in selecting all materials and equipment for the facility. Routine decontamination of the facility during normal replacement of the filters will aid final decommissioning. Any surfaces in the facility that are highly susceptible to hard-to-remove radionuclide contamination will be covered with a removable surface.

4.11.1.9 Postulated Accidents for the Group III Filter Module/HEPA Filter Atmospheric Protection System

Scenarios of postulated accidents for the reference APS are listed in Tables 4.11.7 and 4.11.8. Of the scenarios listed, Accidents 4.11.3 and 4.11.4 have occurred or conditions met for occurrence on a number of occasions for similar types of installations.⁽²⁾ Accident 4.11.1 has undoubtedly occurred, but the frequency of this accident is unknown. Fire or explosion in the APS was not considered since no occurrence has been recorded for similar installations (fuel handling facilities and fuel reprocessing plants),⁽²⁾ and since there are no ignition sources near the filter faces.

TABLE 4.11.7. Minor Accidents for the Group III Filter Module/HEPA Filter Atmospheric Protection System

<u>Accident No. and Description</u>	<u>Sequence of Events</u>	<u>Safety Systems</u>	<u>Release</u>
4.11.1 - Loss of normal electrical power.	1. Short in wire supplying exhaust blower.	1. Air supply fans cease operations. 2. Emergency power diesel generator in ~11 sec.	None.
4.11.2 - Loss of exhaust fan.	1. Electrical short or mechanical malfunction.	1. Air supply fans cease. 2. Spare fan brought into service manually.	None.

4.11.1.10 Facility Costs for the Group III Filter Module/HEPA Filter Atmospheric Protection System

Estimates have been made, in mid-1976 dollars, of capital, operating and levelized unit costs. A complete description of the cost estimate bases, assumptions and definitions is given in Section 3.8.

Capital Costs. Table 4.11.9 gives the capital cost estimate for the reference APS facility. This estimate covers all capital costs specifically resulting from the inclusion of the final filtration facility as an integral part of the FRP described in Section 3.2. These costs also include the ventilation air moving equipment and the effect of incremental additions to utilities such as electrical power; heating, ventilation and air conditioning (HVAC); and compressed air; as well as to the cable, piping and other bulk materials incorporated directly into the final filtration facility. However, general FRP costs for such services as laboratories and warehousing have not been allocated to the final filtration facility.

TABLE 4.11.8. Moderate Accidents for the Group III Filter Module/HEPA Filter Atmospheric Protection System

Accident No. and Description	Sequence of Events	Safety Systems	Release
4.11.3 - Rupture in final HEPA filters because of fatigue--excessive vibration and defective equipment.	<ol style="list-style-type: none"> 1. Glass fiber mat (19 m²) pulled from frame. 2. Airflow increases due to decrease in flow resistance. 	<ol style="list-style-type: none"> 1. Large debris caught in wire screen behind filters. 2. Decrease in flow resistance filter bank alarmed at panel. 3. Flow diverted from affected filter bank to parallel bank and isolated. 	10 ⁻³ of inventory on HEPA filters released via plant stack. Assume equivalent to 9.3 x 10 ⁻³ Ci of 1.5 yr-old, mixed nonvolatile fission products.
4.11.4 - Rupture of HEPA filters because of sudden increase in flow resistance.	<ol style="list-style-type: none"> 1. Fire protection system in walk-in space upstream of HEPA filter malfunctions. 2. Water wets filter. Glass fiber filter mat (19 m²) pulled from frame due to sudden increase in flow resistance. 3. Airflow channeled through space created by faulted filter. 	<ol style="list-style-type: none"> 1. Alarms at fire station, central and local control boards. 2. Exhaust fans are limited to a maximum Δp of 25 cm (10 in.) H₂O across filters. Glass fiber filter mats are designed to withstand at least 25 cm (10 in.) H₂O Δp for 15 min, to allow time for control system response. 3. Sudden increase in flow resistance alarmed at local control board. 4. Sudden loss of flow resistance across filter bank alarmed at local control board. 5. Flow diverted from affected filter bank. 	10 ⁻⁴ of inventory on HEPA filters released via plant stack. Assume equivalent to 9.3 x 10 ⁻⁴ Ci 1.5 x yr-old, mixed nonvolatile fission products.

TABLE 4.11.9. Capital Cost Estimate for the Group III Filter Module/HEPA Filter Atmospheric Protection System

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		20	1,680	240	1,920
Buildings and structures		137	1,150	1,650	2,800
Bulk materials		3	240	40	280
Site improvements		—	—	—	—
Subtotal of direct site construction costs		160	3,070	1,930	5,000
Indirect site construction costs	40	30	680	920	1,600
Total field cost	40	190	3,750	2,850	6,600
Architect-engineer services					1,200
Subtotal					7,800
Owner's cost				2,200	
Total facility cost					10,000
Estimate accuracy range					±25%

The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation, with the exception of working capital, the costs associated with the ventilation system upstream of the final filtration facility, and the costs associated with the ventilation system downstream from the discharge end of the exhaust blower, up to and including the stack.

Operating Costs. Table 4.11.10 shows the operating cost components for the reference system. Direct labor costs are based on the manpower schedule in Table 4.11.3. Supplies and utilities costs are derived from the information in Table 4.11.4. The cost of replacement filters is included in the miscellaneous cost category. The cost of electricity is the major component in the total operating cost, accounting for about 60% of the cost. Maintenance material's costs are estimated at 3% of the initial cost of major equipment. Overhead and miscellaneous costs are calculated as discussed in Section 3.8.

TABLE 4.11.10. Operating Cost Estimate for the Group III Filter Module/HEPA Filter Atmospheric Protection System

Cost Element	Annual Costs, \$1000s
Direct labor	40
Process materials	0
Utilities	320
Maintenance materials	60
Overhead	70
Miscellaneous	50
Total	540 +50% -25%

4.11.13

Levelized Unit Cost. Table 4.11.11 gives the total levelized unit cost, including the levelized capital and operating components. The calculation assumes private ownership of the facilities and a 15-yr economic life.

TABLE 4.11.11. Levelized Unit Cost Estimate for the Group III Filter Module/HEPA Filter Atmospheric Protection System

<u>Cost Element</u>	<u>Unit Cost, \$/kg HM</u>
Levelized capital charge	1.25
Levelized operating charge	.25
Levelized total unit cost	1.50 +35%

4.11.1.11 Facility Construction Requirements for the Group III Filter Module/HEPA Filter Atmospheric Protection System

Many factors relating to site preparation and facility construction for the reference APS may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating the impact of construction activities.

Project Schedules and Construction Manpower. The schedule for engineering, procurement and construction, as well as the estimate of the field labor force for construction, are both integrated with the schedules and estimates for the FRP (see Section 3.2.3.7). The field labor force estimated for the construction of the final filtration facility is tabulated below:

	<u>Man-hours, 1000s</u>
Manual field labor	40
Nonmanual field labor	190
Total field labor	230

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials and services provided at the site of the FRP, while offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is shown below:

	<u>Costs, \$1000s</u>
Onsite	3,000
Offsite	7,000
Total	10,000

Site Requirements. Land commitments for the final filtration facility are included with those of the FRP.

4.11.14

Water. About 3400 m^3 (0.9×10^6 gal) of water are required during the construction period.

Construction Materials. Materials committed to facility construction are:

Concrete	$2,300 \text{ m}^3$	($3,000 \text{ yd}^3$)
Steel	545 MT	(600 tons)
Copper	0.4 MT	(0.5 tons)
Zinc	negligible	
Aluminum	negligible	
Lumber	120 m^3	(50 MFBM)

Energy. Energy resources used during construction are:

Propane	26 m^3	(7,000 gal)
Diesel fuel	265 m^3	(70,000 gal)
Gasoline	190 m^3	(50,000 gal)
Electricity		
Peak demand	200 kW	
Total consumption	130,000 kWh	

Transportation Requirements

No separate transportation requirements for the final filtration facility have been identified beyond those for the FRP.

4.11.1.12 Effects of Fuel Cycle Options

The reference process for the FRP APS based on Group III filter modules and HEPA filters assumes reprocessing of LWR fuel and recycling the retrieved uranium and plutonium. The following alternative fuel cycle modes have also been assessed insofar as they relate to the reference system.

No Recycle. Eliminating the fuel reprocessing operation does away with the reprocessing plant requirement. Accordingly, no APS is required.

Uranium Recycle Only, with Plutonium to a Repository. This alternative is expected to generate about the same amount of dissolver and process off-gas as the uranium and plutonium recycle case.

Uranium Recycle Only, with Plutonium to High-Level Waste (HLW). This alternative would generate about the same quantity of dissolver and process off-gas as the uranium and plutonium recycle case.

4.11.2 Sand Filter/HEPA Filter Atmospheric Protection System

An alternative APS for the reference FRP would employ a deep-bed graded sand filter as the prefilter. The final stage would be a HEPA filter bank. The graded sand filter would provide a large-capacity, efficient trap for most of the larger airborne particles and would be 99+% efficient for submicron-sized particles. Bed life for the sand filter is expected to be

20 years or more. The actual life is determined by the concentration of dust entering the filter and tolerable pressure drop for the exhaust blowers.

The deep-bed sand filter provides a barrier that protects the APS against process upsets, severe impacts from tornadoes, and seismic shocks; in addition, it is nearly indestructible by fire. The sand filter's efficiency is affected little, if at all, by temperature and temperature fluctuations; the filter is inert to chemical attack and has a large capacity for loading. The sand filter's advantages must be weighed against its much higher capital cost (two times greater than that of the Group III filter module/HEPA filter APS or of the deep-bed glass fiber filter/HEPA filter system described in the next section), its pressure drop, and resulting operating costs, and the much larger commitment of land. Another disadvantage of sand filtration is the large volume of sand and gravel that may require removal for terminal storage at the end of the bed life.

4.11.2.1 Alternatives for the Deep-Bed Sand Filter

The deep bed sand filter selected for this report is uniquely designed for the conditions of the reference FRP APS. Some latitude can be exercised in the selection of the coarser grades of gravel and the air distribution systems that support the layers of finer sand. Modifications that may be tolerable from a performance specification standpoint would provide only marginal savings in cost, if any. The construction of the filter must be preceded by a demonstration that the fine sand and the depths of the layers chosen will provide the design efficiency. This constraint does permit some options in sources of sand and quality, but it would be inadvisable to greatly change the sand specification significantly without a substantial experimental program to evaluate the performance of the altered design. The potential advantages of using alternative materials that must be thoroughly tested appear to be obviated by the development cost.

4.11.2.2 Design Basis for the Sand Filter/HEPA Filter Atmospheric Protection System

The design basis for the sand filter/HEPA filter APS is the same as that described for the Group III filter module/HEPA filter in Section 4.11.1.2. In addition, the design of the deep-bed sand filter is patterned after those developed at Hanford and Savannah River. These filters are described in Reference 3, which gives performance data and an extensive bibliography.

Particle removal efficiency for a deep-bed sand filter can approach that for a HEPA filter; experience has shown the filters to be about 99% efficient for a 0.7- μm particle.^(4,5,6) When used as a prefilter upstream of a final HEPA filter bank, a nominal design efficiency of 90% is credited to the installation. This is a conservative efficiency, perhaps by a factor of 10; however, until such a filter has been proven following installation, the lesser efficiency is appropriate for estimating emissions. Several factors can alter sand bed efficiency; efficiency measurements on an actual, scaled assembly using the same cross section of graded sand and gravel are recommended before proceeding with an installation.

The removal efficiency of the HEPA filters on installation is at least 99.97% for 0.3- μm particles. A conservative efficiency of 99.9% is assumed for estimating effluent release. The nominal capacity of each HEPA filter module is 28 m³/min (1,000 cfm) of exhaust air.

4.11.2.3 Process for the Sand Filter/HEPA Filter Atmospheric Protection System

The basic process for all alternative FRP atmospheric protection systems is the same, and is described in the introductory remarks to Section 4.11. Figure 4.11.2 is a process flow diagram for the APS. The type of prefilter used determines the specific route and treatment for the off-gas passing through the APS.

With the sand filter/HEPA filter APS, off-gas from the FRP enters the sand prefilter and is distributed through ducts along the bottom of the sand bed. The air moves upward through successively finer layers of gravel, then sand. The filtered air is drawn with exhaust fans from the space over the sand, and either through a back-up filter system or directly to the stack. The design face velocity of the air through the bed is around 1.5 m/min (5 fpm); at this face velocity the pressure drop is around 17 to 25 mm (7 to 10 in.).

4.11.2.4 Facility Description for the Sand Filter/HEPA Filter Atmospheric Protection System

Figures 4.11.4 and 4.11.5 show the arrangement of the facility that houses the sand filter/HEPA filter APS at the reference FRP. The location of this facility within the FRP site was shown earlier in Figure 4.11.1. The facility is a Category I structure, designed to withstand design basis tornadoes, earthquakes, and floods.

Deep-bed Sand Filter. The sand filter is housed in a massive, reinforced concrete building that measures about 48 x 94 x 6 m (156 x 308 x 20 ft) and contains three separate filter bays. Collectively, the three bays provide a total filter surface area of 3900 m² (42,000 ft²). About 5.8 m (19 ft) of the filter is underground. The roof is supported by concrete columns. An inlet tunnel allows air to enter the bottom of the filter bed. Air distribution trenches are provided across the bottom of the filter at 6-m (20-ft) intervals. From these distribution trenches, air passes through stainless steel support gratings into a single layer of hollow tiles having slotted openings on one side. This layer of hollow tiles is inverted over the distribution trenches and serves to distribute the air to the first layer of coarse gravel in the filter bed. Provisions are made for draining off any liquids through sumps. Monitoring, sampling, testing ports, and delivery lines are provided.

The deep-bed sand prefilter used in this system is composed of several layers of sand supported on the air distribution structure described above. The bottom layer is heavy gravel covered by a layer of smaller-diameter gravel. Sand is placed in three layers over the gravel. The coarsest layer of sand 3- to 6-mm in diameter, is placed on the gravel bed to a depth of 15 cm; the next finer sand, 1 mm to 3 mm, is layered to a depth of about 30 cm; the finest sand, 0.5 mm to 1 mm, is added to a depth of about 91 cm. The overall depth of the unit is about 2.5 m (8 ft). The finest sand layer is protected with a layer of coarse sand (4-8 mesh) to reduce the erosion from the horizontal flow of air. There is about 2.3 m (7-1/2 ft) of air space above the top layer of the sand. Detailed specification of each sand layer is available; the only sand layer that is critical however, is the finest one.⁽⁷⁾ Sand available locally may not be fine enough (30-50 mesh). The original sand filters used at Hanford required shipments of sand from Eau Claire, Wisconsin. If an untried source of fine sand is selected, the sand from that source should be subjected to efficiency tests in a pilot-scale filter assembly.

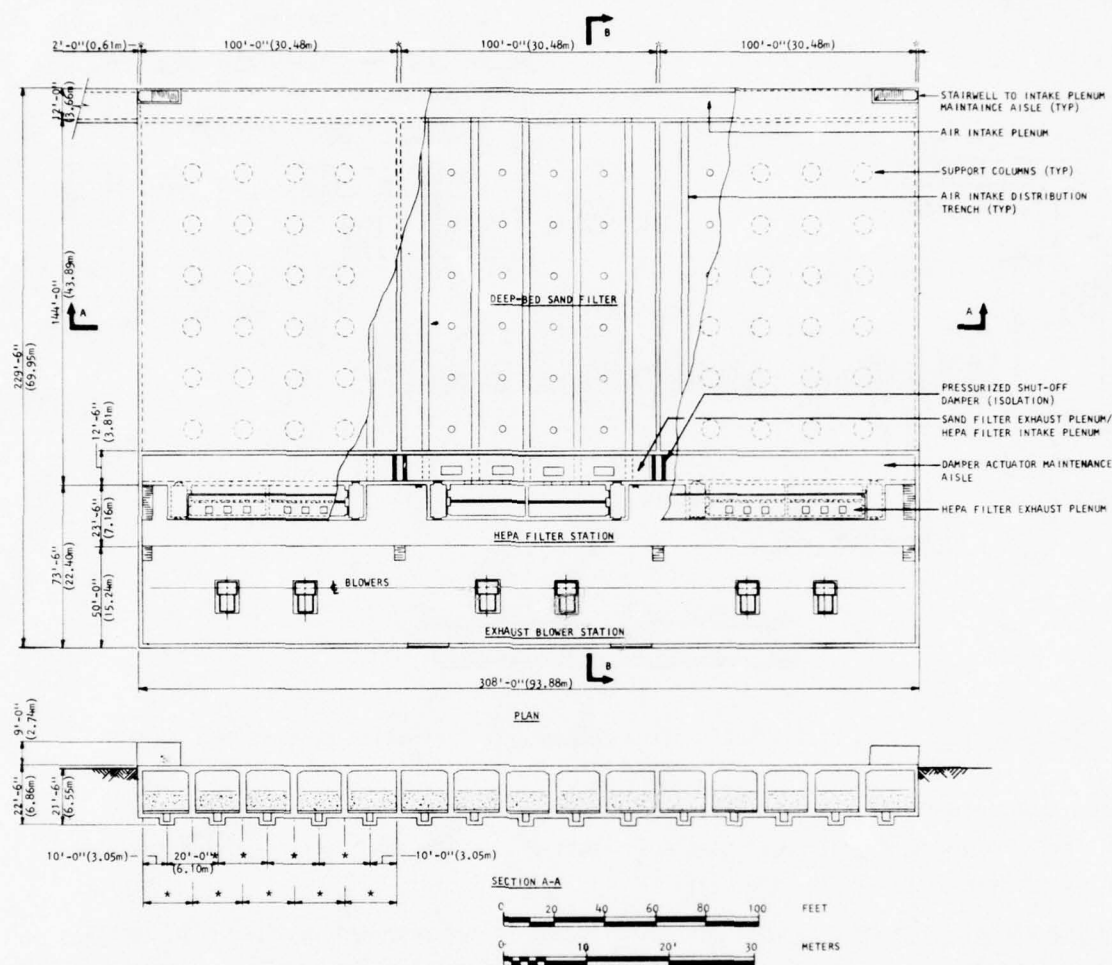


FIGURE 4.11.4. Sand Filter/HEPA Filter Atmospheric Protection System, Plan and Section A-A

HEPA Filter Banks. The HEPA filters are contained within six concrete-walled rooms within the blower station building adjacent to the sand filter. The six rooms are arranged in groups of two. Welded to the walls of each room is a filter mounting frame that holds 40 HEPA filter modules in a 4 x 10 array. The individual filter modules are 61 cm square x 29 cm deep (2 ft square x 11 1/2 in. deep). Air locks and entrances are provided for filter changes; fitting and sample lines are placed for introducing dioctylphthalate (DOP) aerosol to measure filter efficiency.

Monitoring System. Radiation monitoring is provided continuously by beta/gamma detectors mounted near the HEPA filters. For the sand filter, monitoring tubes 15 cm (6 in.) in diameter extend from the roof to the bottom of the bed for radiation surveys. Pressure differential

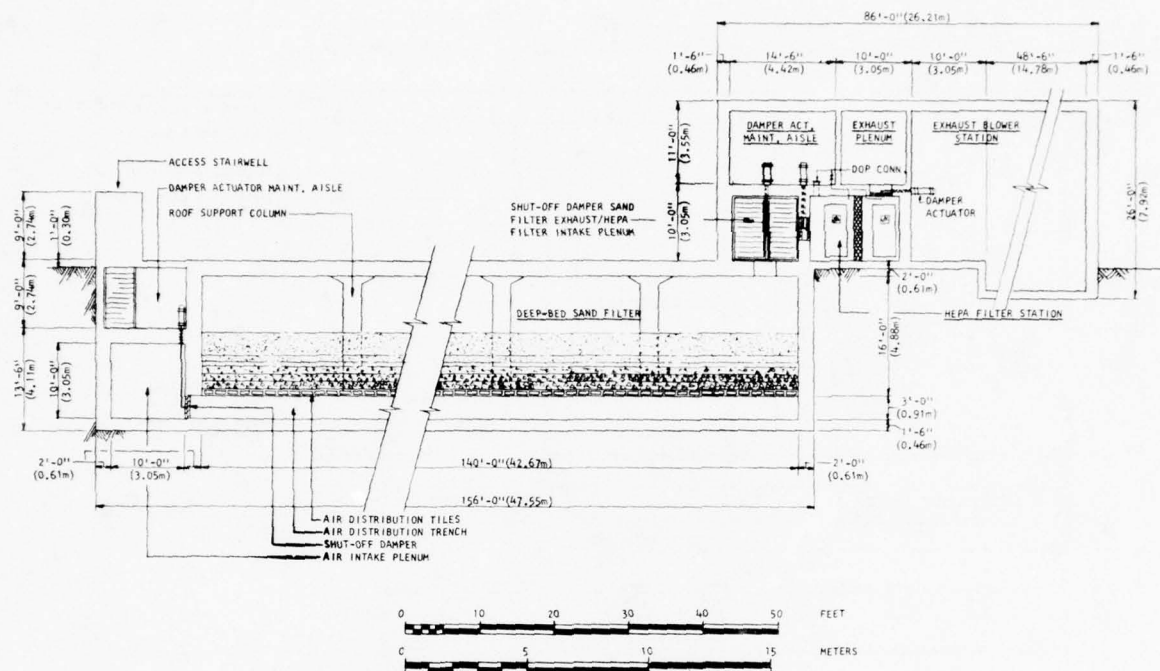


FIGURE 4.11.5. Sand Filter/HEPA Filter Atmospheric Protection System, Section B-B

instruments and associated alarming devices monitor the pressure drop of the HEPA filters. Static lines and probes installed at strategic locations in the sand filter provide the same pressure monitoring services for the prefilter.

Fire Protection System. Exhaust air ducts to the filter room are equipped with debris screens to intercept airborne burning debris before it can enter the air plenum. A smoke detector and a combination rate-of-rise and fixed-temperature detector are provided. Suppression is accomplished by spraying water as a fine mist on the debris screens. Both detectors must be in an alarm condition simultaneously to actuate the water supply.

Air Moving Equipment. Five exhaust blowers provide the motive force for plant ventilation. Each blower is designed for exhausting $1410 \text{ m}^3/\text{min}$ (50,000 cfm) of air at 115 cm (45 in.) water differential pressure. The blower is a centrifugal-type and is driven by a 375 kW electric motor. An identical unit is installed on standby mode during normal operation.

Shielding and Remote Handling Equipment. Change of the HEPA filter units may require placement of temporary shielding panels and use of specially designed tools to release hold-down clamps. Remote tools and shielding will not be necessary if the filter units are changed frequently enough to prevent excessive build up of radioactive material. These choices must be made by operators familiar with the trade-offs between replacement costs and radiation reduction to workers.

4.11.2.5 Operating and Maintenance Requirements for the Sand Filter/HEPA Filter Atmospheric Protection System

The facility operates 24 hr/day, 7 days/wk, the year around. Normal activities include monitoring pressure drop across filters, sampling, and normal maintenance and replacement activities. All normal process operations and filter removal and installation are handled manually. In all cases, the dose is controlled and limited to less than 1 mrem/hr. HEPA filters will be replaced in accordance with pressure requirements and prescribed radiation limits. A parallel airflow design allows more than two-thirds of the HEPA filters to be used while a bank of filters is being replaced. Prior to use, a new filter section will be tested using DOP aerosols. Detailed instructions for installation and testing are available.⁽¹⁾

Staffing. Estimated staffing requirements for the facility are the same as those given in Section 4.11.1.5 for the Group III filter module/HEPA filter APS.

Supplies and Utilities. Table 4.11.12 shows supplies used in the sand filter/HEPA filter APS operations. Utility requirements are the same as those given in Section 4.11.1.5 for the Group III filter module/HEPA filter APS.

TABLE 4.11.12. Supply Requirements for the Sand Filter/
HEPA Filter Atmospheric Protection System

<u>Supply</u>	<u>Annual Requirement</u>
HEPA filters	80
Detergent (for decontamination and cleanup)	150 kg

4.11.2.6 Secondary Radioactive Wastes for the Sand Filter/HEPA Filter Atmospheric Protection System

Secondary radioactive wastes for the sand filter/HEPA filter APS are the same as those given in Section 4.11.1.6.

4.11.2.7 Facility Emissions for the Sand Filter/HEPA Filter Atmospheric Protection System

Facility emissions are the same as those given in Section 4.11.1.7.

4.11.2.8 Decommissioning Considerations for the Sand Filter/HEPA Filter Atmospheric Protection System

At the end of its operating life, the facility housing the sand filter/HEPA filter APS will be decommissioned. Plans for decommissioning the facility must provide for appropriate decontamination and monitoring equipment to assess actinide and fission product buildup during the life of the plant. Ease of retirement and removal of the sand and gravel should be an important consideration in selecting all materials and equipment necessary for the facility. It is expected that the sand will be excavated (remotely if necessary), packaged, and transported to a repository. Routine decontamination of the facility, except for the sand filter area, will aid

in final decontamination. Any facility structure surfaces that are highly susceptible to hard-to-remove radionuclide contamination will be covered with a removable surface but may be difficult to retain in the sand filter area for the life of the FRP.

4.11.2.9 Postulated Accidents for the Sand Filter/HEPA Filter Atmospheric Protection System

Accident scenarios for the sand filter/HEPA filter APS are the same as those described in Tables 4.11.7 and 4.11.8, Section 4.11.1.9.

4.11.2.10 Facility Costs for the Sand Filter/HEPA Filter Atmospheric Protection System

Estimates have been made, in mid-1976 dollars, of capital, operating and levelized unit costs. A complete description of the cost estimate basis, assumptions and definitions is given in Section 3.8.

Capital Costs. Table 4.11.13 gives the capital cost estimates for the sand filter/HEPA filter APS. This estimate covers all capital costs specifically resulting from the inclusion of the final filtration facility as an integral part of the FRP described in Section 3.2. These costs also include the ventilation air moving equipment and the effect of incremental additions to utilities, such as electricity; heating ventilation, and air conditioning (HVAC); and compressed air; as well as the cable, piping and other bulk materials incorporated directly into the final filtration facility. However, general FRP costs for services such as laboratories and warehousing have not been allocated to the APS.

TABLE 4.11.13. Capital Cost Estimate for the Sand Filter/HEPA Filter Atmospheric Protection System

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Non-Manual	Manual	Material	Labor	Total
Major equipment		5	370	100	470
Buildings and structures		530	2,570	6,400	8,970
Bulk materials		15	160	200	360
Site improvements					
Subtotal of direct site construction costs		550	3,100	6,700	9,800
Indirect site construction costs	140	110	2,500	3,200	5,700
Total field cost	140	660	5,600	9,900	15,500
Architect engineer services					2,800
Subtotal					18,300
Owner's cost					5,700
Total facility cost					24,000
Estimate accuracy range					±30%

The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation with the exception of working capital, the costs associated with the ventilation system upstream of the final filtration facility, the costs associated with the ventilation system downstream from the discharge end of the exhaust blower up to and including the stack.

Operating Costs. Table 4.11.14 tabulates the operating cost components for the reference system. Direct labor costs and utilities are the same as for the Group III filter module/HEPA filter APS (Section 4.11.1). Maintenance materials costs are estimated at 3% of major equipment cost. Overhead and miscellaneous costs are calculated as indicated in Section 3.8. Costs of HEPA filter replacement are included under miscellaneous costs.

Levelized Unit Costs. The total levelized unit cost, including the levelized capital and operating components, is shown in Table 4.11.15. The cost calculation assumes private ownership of the facilities and a 15-yr economic life.

TABLE 4.11.14. Operating Cost Estimate for the Sand Filter/HEPA filter Atmospheric Protection System

Cost Element	Annual Costs, \$1000s
Direct labor	40
Process materials	0
Utilities	320
Maintenance materials	15
Overhead	45
Miscellaneous	80
Total	500 +50% -25%

TABLE 4.11.15. Levelized Unit Cost Estimate for the Sand Filter/HEPA Filter Atmospheric Protection System

Cost Element	Unit Cost, \$/kg HM
Levelized capital charge	2.95
Levelized operating charge	.25
Levelized total unit cost	3.20 ±40%

4.11.2.11 Construction Requirements for the Sand Filter/HEPA Filter Atmospheric Protection System

Many factors relating to site preparation and facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information which follows provides a basis for evaluating the impact of construction activities.

4.11.22

Project Schedules and Construction Manpower. The schedule for engineering, procurement and construction as well as the estimate of the field labor construction force, for the sand filter/HEPA filter APS is integrated with the estimates and schedules for the FRP. The field labor force is tabulated below:

	Man-hours, 1000s
Manual field labor	660
Nonmanual field labor	<u>140</u>
Total field labor	800

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials and services provided at the site of the FRP, while offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is shown below:

	Costs, \$1000s
Onsite	10,500
Offsite	<u>13,500</u>
Total	24,000

Site Requirements. No additional site or land requirements beyond those for the FRP are identifiable.

Water. About 1200 m^3 (3.2×10^6 gal) of water are needed during construction.

Construction Materials. Materials committed to facility construction are:

Concrete	11,000 m^3	(14,800 yd^3)
Steel	1,900 MT	(2,000 tons)
Copper	0.9 MT	(1 ton)
Zinc	0.5 MT	(0.5 ton)
Lumber	700 m^3	(300 MFBM)
Graded gravel, 1/4 to 3-in.	3,800 m^3	(5,000 yd^3)
Graded gravel, #50 to #8	5,600 m^3	(7,400 yd^3)

Energy. Energy resources needed during construction are:

Propane	95 m^3	(25,000 gal)
Diesel fuel	950 m^3	(250,000 gal)
Gasoline	600 m^3	(160,000 gal)
Electricity		
Peak demand	450 kW	
Total consumption	450,000 kWh	

Transportation Requirements. No separate transportation requirements for the sand filter/HEPA filter APS have been identified beyond those for the FRP.

4.11.2.12 Effects of Fuel Cycle Options

The process for the reference FRP APS based on a deep-bed sand filter and HEPA filter assumes reprocessing of LWR fuel and recycling the retrieved uranium and plutonium. The following alternative fuel cycle modes have also been assessed insofar as they relate to this system.

No Recycle. Eliminating the fuel reprocessing operation does away with the reprocessing plant requirement. Accordingly, no APS is required.

Uranium Recycle Only, with Plutonium to a Repository. This alternative is expected to generate about the same amount of dissolver and processing off-gas as in the uranium and plutonium recycle case.

Uranium Recycle Only, with Plutonium to High-Level Waste (HLW). This alternative would generate about the same quantity of dissolver and processing off-gas as in the uranium and plutonium recycle case.

4.11.3 Deep-Bed Fiber Filter/HEPA Atmospheric Protection System

A third alternative APS would employ a deep-bed glass fiber filter as the prefilter. As with the other two APSs, the final stage would be a HEPA filter bank. The deep-bed glass fiber filter would provide a large-capacity, efficient trap for most of the larger airborne particles.

An extensive research effort was applied to characterizing and testing deep-bed glass fiber filters in the 1950s. This effort resulted in the ability to make reasonably accurate predictions of bed efficiency.⁽⁸⁾ The first large-scale application of this type of filter in an FRP was a bed of glass fibers 30 μm in diameter freely packed to a depth of 2.1 m (84 in.). This free-packed prefilter was followed by a high efficiency fiber glass filter mat 2.5 cm (1 in.) deep, contained in conventional "V"-type filter assemblies. The combined efficiency of the prefilter and the final filter was about 99.9% for actual service conditions with inlet aerosol particles in the range of 0.2 to 0.7 μm in diameter.⁽⁸⁾ This filter exhibited an initial pressure drop of 10 cm (4 in.) water gauge when the face velocity was about 0.25 m/sec (50 fpm).

Deep-bed glass fiber filters have been used primarily as prefilters to remove the larger particles, representing the bulk of solids, carried in an off-gas stream. When used for this purpose, these filters can be tailored to an efficiency greater than 90% for 0.3- μm -sized particles. The most recent deep-bed glass fiber filter installation at the Department of Energy (DOE) Idaho Falls Chemical Processing Plant showed a clean filter efficiency of about 80% for test aerosol particles (dioctylphthalate) having a median diameter of 0.7 μm .⁽⁹⁾ The mass decontamination factor for the filter is calculated to be 2000, taking into account larger particles that could be present. The Idaho Falls filter uses 5 trays containing glass fibers

packed to densities ranging from 11.3 to 48.4 kg/m³ (0.7-3.0 lb/ft³). These trays are stacked five in a series and mounted in four below-ground bays. The trays are sealed to steel imbedded in the walls and can be removed for terminal storage, if required.

The life of the deep-bed glass fiber filter will depend upon the circumstances that determine dust loading. If gases that react with each other or form solids can be eliminated or greatly reduced, the deep-bed glass fiber filter would probably last 15-20 years before replacement is needed due to excessive pressure drop or deterioration in efficiency.

Among the advantages of the deep-bed glass fiber filter are its inertness to most chemicals other than hydrofluoric acid and the buffer it provides both from upstream process upsets and from overpressures due to tornadoes. In addition, deep-bed glass fiber filters are relatively insensitive to moisture, have a low pressure drop even though the face velocity is high, can be made to survive in earthquakes, are low in maintenance costs, and are not susceptible to fire.

4.11.3.1 Alternatives for the Deep-Bed Glass Fiber Filters

Prepacked, deep-bed glass fiber tray and frame units were selected for the reference deep-bed glass fiber filter/HEPA filter APS. In an alternative design, as mentioned above, the glass fibers could be freely packed into a large concrete housing and compressed to the required density by large hold-down screens supported by steel plates imbedded in the walls. With the free-packed bed, great care must be exercised to maintain a uniform packing over the large area of the housing. The prepacked, modular units selected for the reference APS give greater assurance of uniform packing and, therefore, efficiency. The free-packed bed cannot be dismantled readily for final storage of the filter medium; when the free-packed filter medium needs replacing, a totally new unit must be built, including the concrete vault and all appurtenances. The failure of a deep-bed free-packed filter should be anticipated by about one year to allow for construction of new facilities.

4.11.3.2 Design Basis for the Deep-Bed Glass Fiber Filter/HEPA Filter Atmospheric Protection System

The design basis is the same as that described for the reference facility, Section 4.11.1.2.

4.11.3.3 Process for the Deep-Bed Glass Fiber Filter/HEPA Filter Atmospheric Protection System

The process for the deep-bed glass fiber filter/HEPA filter APS is summarized in the introductory remarks to Section 4.11.

4.11.3.4 Facility Description for the Deep-Bed Glass Fiber Filter/HEPA Filter Atmospheric Protection System

The location of the facility that houses the deep-bed glass fiber filter/HEPA filter APS within the reference FRP is the same as for the other two alternative facilities and is shown in Figure 4.11.1. Figures 4.11.6 and 4.11.7 show the facility arrangement for the reference APS. The facility is a Category I structure designed to withstand design-basis tornadoes, earthquakes, and floods.

Deep-bed Glass Fiber Filter. The prefilter vault that houses the deep-bed glass fiber filter is approximately 18 x 36 x 5.8 m (60 x 118 x 19 ft) and is separated into four bays. An air intake plenum at one end of the vault allows ventilation air to enter; the air is directed through flow slots into each bay. The three interior walls that separate the vault into four bays support the cross beam members, to which are fastened the frames that support the glass fiber beds. The floor of the vault is sloped along its length to collection sumps. The roof of the vault is removable in sections and is located 0.3 m (1 ft) below grade.

The deep-bed glass fiber prefilter has an area of 500 m² (5400 ft²) so that an airflow of 7080 m³/min (250,000 cfm) will not exceed a superficial gas face velocity of 19 m/min (62 ft/min). The filter is designed for gas upflow through five layers of separately-supported, packed media with the following thicknesses and glass fiber packing densities:

Layer, Bottom to Top	Bed Thickness, cm	Packing Density, kg/m ³
1	38	11
2	38	11
3	46	24
4	46	24
5	46	48

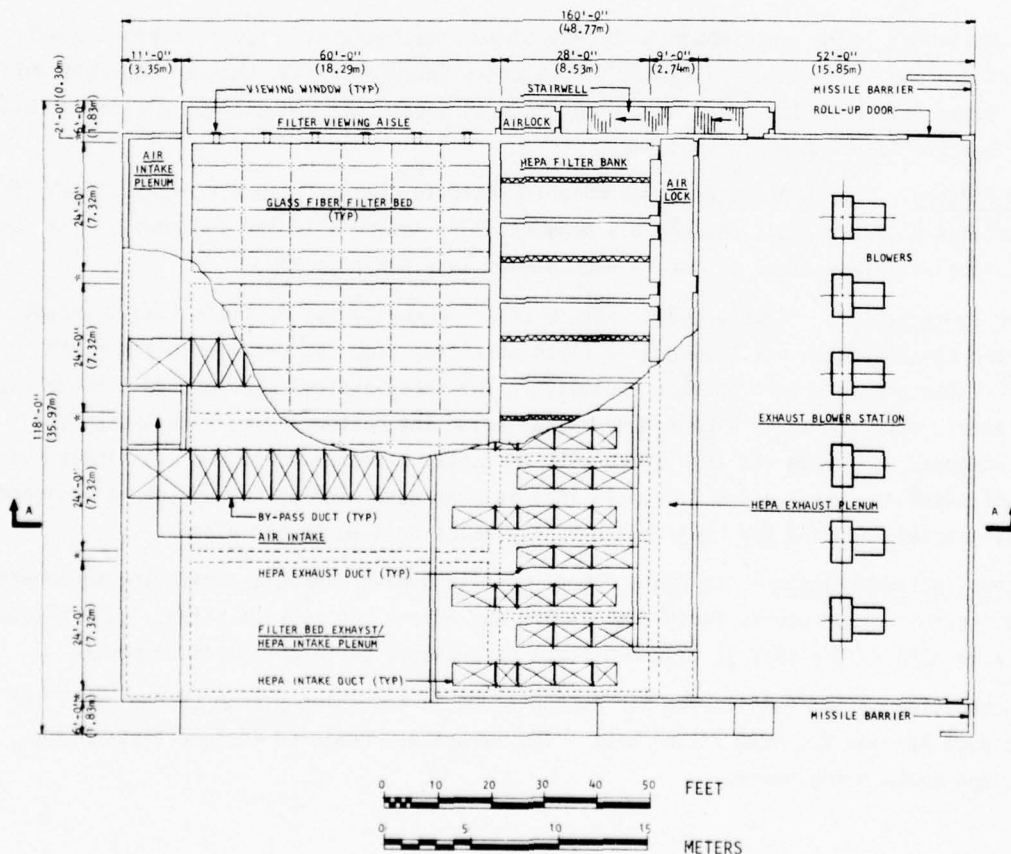


FIGURE 4.11.6. Deep-Bed Glass Fiber Filter/HEPA Filter Atmospheric Protection System, General Plan

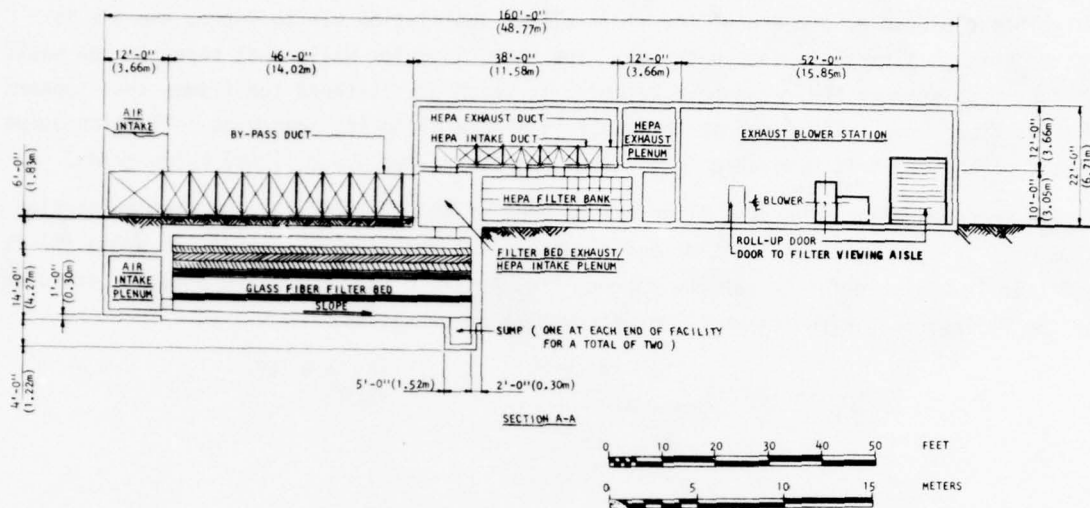


FIGURE 4.11.7. Deep-Bed Glass Fiber Filter/HEPA Filter Atmospheric Protection System, Section A-A

The five individual layers are supported by stainless steel screens wired to support pipes. The resulting frame is mounted and sealed to the cross beams extending between concrete walls. The glass fiber filter vault is equipped with ducts through which ventilation air can be by-passed if the prefilter requires flushing.

HEPA Filters. The HEPA filter banks comprise walk-in plenums with air locks. Each filter plenum contains 36 individual, replaceable modules (2 ft square x 11-1/2 in. deep). The modules are mounted to stainless steel frames in each plenum in a 3 x 12 array.

Water Spray System. Since plugging attributable to unexpected particle loading might occur, water spray systems are provided to flush particles from the deep-bed glass fiber prefilter if the pressure drop becomes excessive. The spray systems are located between the top two layers, with the spray directed downward; below the bottom layer, with the spray directed upwards; and above the top layer, with the spray directed downward. The spray systems are made of stainless steel pipes 7.5 cm (3 in.) in diameter. The bottom system is equipped with spray nozzles, and the two upper systems have holes drilled in the pipes.

Process Instrumentation. The glass fiber prefilters have pressure monitoring equipment to determine pressure drops across individual layers and across the overall filter. The pressure drop for each HEPA filter bank is also monitored by pressure differential instruments.

The condition of the ventilation air is monitored in the inlet plenum of the prefilter and an outlet duct leaving the HEPA filter area. The parameters measured include temperature, humidity, and smoke entrainment.

Radiation monitoring for the prefilter is accomplished by steel monitor tubes extending from above the roof of the prefilter to the floor of the vault. Area radiation monitors are provided for each HEPA filter bank.

Test Equipment. Connections for introducing dioctylphthalate aerosols into the HEPA filter plenum at its inlet ducting are installed to provide in-place testing of all the HEPA filters. Sample probes are also provided at the exhaust end of the plenums.

Fire Protection System. Exhaust air ducts to the filter room are equipped with debris screens to intercept airborne, burning debris before it can enter the air plenum. Detection is provided by a smoke detector and a combination rate-of-rise and fixed-temperature detector. Suppression is accomplished by spraying water as a fine mist on the debris screens. Both detectors must be in an alarm condition simultaneously to actuate the water supply.

Air Moving System. This system is equipped with 6 centrifugal-type exhaust blowers; one of the six blowers is provided as a spare. Each rates at $1420 \text{ m}^3/\text{min}$ (50,000 cfm) capacity at a pressure differential of 100 cm (40 in.) water gauge and is driven by a 350 kW motor.

Shielding and Remote Handling Equipment. See Section 4.11.2.4.

4.11.3.5 Operating and Maintenance Requirements for the Deep-Bed Glass Fiber Filter/HEPA Filter Atmospheric Protection System

The facility operates 24 hr/day, 7 days/wk, the year around. All normal process operations and filter removal and installation are handled manually. In all cases, the dose is controlled and limited to less than 1 mrem/hr. Normal activities include monitoring pressure drop across filters, sampling, and normal maintenance and replacement activities. HEPA filters will be replaced and prefilters will be washed in accordance with pressure drop requirements and prescribed radiation limits. A parallel airflow design permits two-thirds of the HEPA filters to be used while a bank of filters is being replaced. Prior to use, a new filter section will be tested using dioctylphthalate (DOP) aerosols. Detailed instructions for installation and testing are available.⁽¹⁾

Staffing. Estimated staffing requirements for the reference system are the same as those given in Section 4.11.1.5 for the Group III filter module/HEPA filter APS.

Supplies and Utilities. Supplies used for the deep-bed glass fiber filter/ HEPA filter APS are shown in Table 4.11.16. Utility requirements are the same as those given in Section 4.11.1.5.

4.11.3.6 Secondary Radioactive Wastes for the Deep-Bed Glass Fiber Filter/HEPA Filter Atmospheric Protection System

Secondary radioactive wastes are the same as those characterized for the Group III filter module/HEPA filter APS in Section 4.11.1.6.

4.11.3.7 Facility Emissions for the Deep-Bed Glass Fiber Filter/HEPA Filter Atmospheric Protection System

Facility emissions are the same as those given in Section 4.11.1.7.

TABLE 4.11.16. Supply Requirements for the Deep-Bed Glass Fiber Filter/HEPA Filter Atmospheric Protection System

<u>Description</u>	<u>Annual Requirement</u>
HEPA filters	80
Detergent (for decontamination and cleaning)	300 kg

4.11.3.8 Decommissioning Considerations for the Deep-Bed Glass Fiber Filter/HEPA Filter Atmospheric Protection System

The facility that houses the deep-bed glass fiber filter/HEPA filter APS is designed to have a useful operational life of 20 years. At the end of its operating life, the reference APS facility is expected to be relatively free of contamination, with the exception of the removable HEPA filters. Although the deep-bed glass fiber filters are designed to be removed only at decommissioning, water spray systems are provided to flush particles and unexpected filter loading materials as required. Regular replacement of the HEPA filters, as well as routine removal of contamination from the deep-bed filters and from the facility itself, will aid in decommissioning the facility. Ease of retirement is an important consideration in selecting materials, monitoring devices and general equipment for the facility. Any facility structure surfaces that are highly susceptible to hard-to-remove radionuclide contamination will be covered with a removable surface. Such a surface may be difficult to retain in the deep-bed glass fiber filter area for the life of the FRP.

4.11.3.9 Postulated Accidents for the Deep-Bed Glass Fiber Filter/HEPA Filter Atmospheric Protection System

The accidents postulated in Tables 4.11.7 and 4.11.8 apply here. Section 4.11.1.9 applies as well to the deep-bed glass fiber filter/HEPA filter APS.

4.11.3.10 Facility Costs for the Deep-Bed Glass Fiber Filter/HEPA Filter Atmospheric Protection System

Estimates have been made, in mid-1976 dollars, of capital, operating, and levelized unit costs. A complete description of the cost estimate bases, assumptions and definitions is given in Section 3.8.

Capital Costs. The capital cost estimate for the reference system is shown in Table 4.11.17. This estimate covers all capital costs specifically resulting from the inclusion of the final filtration facility as an integral part of the FRP described in Section 3.2. These costs also include the ventilation air moving equipment and the effect of incremental additions to utilities such as electricity; heating, ventilation, and air conditioning, (HVAC); and compressed air; as well as the cable, piping and other bulk materials incorporated directly into the final filtration facility. However, general FRP costs for such services as laboratories and warehousing are not allocated to the reference APS.

TABLE 4.11.17. Capital Cost Estimate for the Deep-Bed Glass Fiber Filter/HEPA Filter Atmospheric Protection System

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		27	1,550	350	1,900
Buildings and structures		150	1,220	1,780	3,000
Bulk materials		13	230	170	400
Site improvements		--	--	--	--
Subtotal of direct site construction costs		190	3,000	2,300	5,300
Indirect site construction costs	50	40	800	1,100	1,900
Total field cost	50	230	3,800	3,400	7,200
Architect-engineer services					1,300
Subtotal					8,500
Owner's cost					2,500
Total facility cost					11,000
Estimated accuracy range					±25%

The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation, with the exception of working capital, the costs associated with the ventilation system upstream of the final filtration facility, and the costs associated with the ventilation system downstream from the discharge end of the exhaust blower up to and including the stack.

Operating Costs. The operating cost components for the reference system are given in Table 4.11.18. Direct labor costs and utilities are the same as for the other APSs. Cost of HEPA filter replacement are included in miscellaneous costs. Maintenance materials costs are estimated at 3% of major equipment cost. Overhead and miscellaneous costs are calculated as indicated in Section 3.8.

TABLE 4.11.18. Operating Cost Estimate for the Deep-Bed Glass Fiber Filter/HEPA Filter Atmospheric Protection System

Cost Element	Annual Costs, \$1000s
Direct labor	30
Process materials	0
Utilities	320
Maintenance materials	40
Overhead	70
Miscellaneous	40
Total	500 +50% -25%

Levelized Unit Costs. Table 4.11.19 shows the total levelized unit cost, including the levelized capital and operating components. The cost calculation assumes private ownership of the facilities and a 15-yr economic life.

TABLE 4.11.19. Levelized Unit Cost Estimate
for the Deep-Bed Glass Fiber
Filter/HEPA Filter Atmospheric
Protection System

<u>Cost Element</u>	<u>Unit Cost, \$/kg HM</u>
Levelized capital charge	1.90
Levelized operating charge	<u>.25</u>
Levelized total unit cost	2.15 +40%

4.11.3.11 Construction Requirements for the Deep-Bed Glass Fiber Filter/
HEPA Filter Atmospheric Protection System

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information which follows provides a basis for evaluating the impact of construction activities.

Project Schedules and Construction Manpower. The schedule for engineering, procurement and construction as well as the estimate of the field labor force for construction are both integrated with the schedules and estimates for the FRP. The field labor force for the reference APS construction is tabulated below:

	<u>Man-hours, 1000s</u>
Manual field labor	230
Nonmanual field labor	<u>50</u>
Total field labor	280

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials and services provided at the site of the FRP, while offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is shown below.

	<u>Costs, \$1000s</u>
Onsite	3,700
Offsite	<u>7,300</u>
Total	11,000

Site Requirements. No additional site requirements or land commitments beyond those for the FRP are identifiable.

Water. About 3800 m^3 (1.0×10^6 gal) of water are required during the construction period.

Construction Materials. Materials committed to facility construction are:

Concrete	$3,000 \text{ m}^3$	(4,000 yd^3)
Steel	730 MT	(800 tons)
Copper	0.5 MT	(0.5 tons)
Lumber	120 m^3	(50 MFBM)

Energy. Energy resources required during construction are:

Propane	30 m^3	(8,000 gal)
Diesel fuel	300 m^3	(80,000 gal)
Gasoline	230 m^3	(60,000 gal)
Electricity		
Peak demand	250 kW	
Total consumption	160,000 kWh	

Transportation Requirements. No separate transportation requirements for the reference facility have been identified beyond those for the FRP.

4.11.3.12 Effects of Fuel Cycle Options

The reference process for the FRP atmospheric protection system based on deep-bed glass fiber filters and HEPA filters assumes reprocessing of LWR fuel and recycling the retrieved uranium and plutonium. The following alternative fuel cycle modes have also been assessed insofar as they relate to this system.

No Recycle. Eliminating the fuel reprocessing operation does away with the reprocessing plant. Accordingly, no APS is required.

Uranium Recycle Only, with Plutonium to a Repository. This alternative is expected to generate about the same amount of dissolver and processing off-gas as in the uranium and plutonium recycle case.

Uranium Recycle Only, with Plutonium to High-Level Waste (HLW). This alternative would generate about the same quantity of dissolver and processing off-gas as in the uranium and plutonium recycle case.

4.11.4 Other Alternatives for the Fuel Reprocessing Plant Atmospheric Protection System

Conventional air cleaning systems used widely in industry were considered before selecting the reference alternatives. Electrostatic precipitation, bag filters, and wet scrubbing systems could be entertained as possible alternatives to the filtration systems selected. Certain performance characteristics of these other alternative APSs, however, make them appear less suitable for use in the reference FRP.

4.11.4.1 Electrostatic Precipitators

Electrostatic precipitators remove particles efficiently by first imparting a unipolar charge to the particles, then passing the particles through a high voltage field. High voltage electrode wires are centered between vertical plates which are the collectors. Although widely used in industry for reducing emissions, these air cleaners have features that make their use in an FRP unattractive. Under close control, an electrostatic precipitator can be 99% efficient; however, efficiency can drop to zero in a power failure or other electrical equipment malfunction. Another drawback is the potential for deposited particles to slough off the collector plates. For these reasons, electrostatic precipitators are not used in nuclear facilities.

4.11.4.2 Bag Filters

Fabric filters in the form of long vertical tubes are used in industries where an airborne effluent is to be recovered. Efficiencies of greater than 99% are achieved. While this type of filter could be applied as a prefilter in an APS, efficiencies would generally not be adequate as a final filter. Bag filters, too, would require greater space and are more expensive to maintain than the prefilters discussed in Sections 4.11.1-4.11.3.

4.11.4.3 Wet Collectors

A variety of wet scrubber systems are used for removing particles and gases from effluent streams. Most applications do not insure the removal of submicron-sized particles, although venturi scrubbers and other scrubbers imparting great energy to the fluid can provide 99% removal. A principal disadvantage when applied to removing radioactive particles is the creation of a liquid waste stream. Thus, the scrubber fluid would have to be converted to a form suitable for disposal. Scrubber systems for the entire FRP ventilation air would be very large, requiring more energy and materials than passive systems. Efficiency is dependent on maintaining control of scrubber flow; hence, this requirement introduces the potential of variable efficiency, which could not be tolerated for the reference FRP.

4.11.5 Physical Protection and Safeguard Requirements for the Fuel Reprocessing Plant Atmospheric Protection System

The physical protection discussion in Section 4.8.4 applies as well to the FRP APS.

REFERENCES FOR SECTION 4.11

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4. R. A. Moyer, J. H. Crawford, and R. E. Tatum, "Deep-Bed Sand Filter at Savannah River Laboratory," Proceedings of the Thirteenth AEC Air Cleaning Conference, San Francisco, California, 12-15 August 1974. CONF-740807, Vol. 1, pp. 632-640, 1974.
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6. G. D. Schuff, D. B. Zippler, D. C. Guyton, "Deep-Bed Filter Performance Tests," Proceedings of the 12 AEC Air Cleaning Conference, CONF 720823, p. 596-618, August 28-31, 1972.
7. Reference 1, p. 231.
8. A. G. Blasewitz, and W. C. Schmidt, "Treatment of Radioactive Gases," Progress in Nuclear Energy Series III., Vol. 3, Process Chemistry. Pergamon Press, Oxford, pp. 414-425, 1961.
9. Reference 1, p. 236-237.

ACRONYMS LIST

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A-E	architect-engineer	EPC	engineering, procurement, and construction
AAPG	American Association of Petroleum Geologists	ER	environmental report
ACVSF	air-cooled vault storage facility	ERDA	Energy Research and Development Administration
AEC	Atomic Energy Commission	ESFS	engineered safety features systems
AECL	Atomic Energy of Canada, Limited	ESPS	essential spray pond system
AFR	away from reactor (spent fuel storage)	FFTF	Fast Flux Test Facility
AGNS	Allied General Nuclear Services	FP	fission product
ALARA	as low as reasonably achievable	FPF	fuel packaging facility
AMAD	aerodynamic median activity diameter	FRP	fuel reprocessing plant
AP	activation product	FRPF	fuel residue packaging facility
API	American Petroleum Institute	FRSSF	fuel residue subsurface storage facility
APS	atmospheric protection system	FRVSF	fuel residue vault storage facility
BFRSS	Barnwell Fuel Receiving and Storage Station	FRW	fuel residue waste
BIF	bitumen immobilization facility	FSA	fuel storage area
BPPF	Barnwell Plutonium Product Facility	FSAR	Final Safety Analysis Report
BTU	British thermal unit	FSB	fuel storage basin
BWR	boiling water reactor	FTF	fuel transfer facility
CANDU	Canadian heavy water reactor	FTP	fuel transfer platform
CDC	canister decontamination cell (cubicle)	GEIS	Generic Environmental Impact Statement
CFR	<u>Code of Federal Regulations</u>	HCF	hulls compaction facility
CIF	cement immobilization facility	HEPA	high-efficiency particulate air (filter)
CRWM	Committee on Radioactive Waste Management	HEU	highly enriched uranium
CUP	cask unloading pool	HLLW	high-level liquid waste
CVCS	chemical and volume control system	HLW	high-level waste
CW	canistered waste	HM	heavy metal
CWMS	Generic Environmental Impact Statement on Commercial Radioactive Waste Management, DOE-1559	HMA	hot maintenance area
CWTF	cask weld test facility	HMF	hulls melting facility
DCSF	dry caisson storage facility	HPF	hulls packaging facility
DF	decontamination factor	HTD	hulls transfer device
DOE	Department of Energy	HTGR	high temperature gas-cooled reactor
DOG	dissolver off-gas	HVAC	heating, ventilation, and air conditioning
DOP	dioctylphthalate	IAEA	International Atomic Energy Agency
DOT	Department of Transportation	IBC	in-bed combustion
DTPA	diethylenetriamine pentaacetic acid	ICPP	Idaho Chemical Processing Plant
ECWS	essential cooling water system	IFSF	independent fuel storage facility
		IIPSF	independent interim plutonium oxide storage facility

ILLW	intermediate-level liquid waste	PFRF	packaged fuel receiving facility
ILW	intermediate-level waste	PNL	Pacific Northwest Laboratory
INEL	Idaho National Engineering Laboratory	POG	process off-gas
IPSF	interim plutonium oxide storage facility	PSAR	preliminary safety analysis report
ISFS	independent spent fuel storage	PWR	pressurized water reactor
ISFSB	independent spent fuel storage basin	R&D	research and development
ISFSF	independent spent fuel storage facility	RAA	restricted access area
LAA	limited access area	RBOF	receiving basin for offsite fuel, Savannah River Plant
LEU	low-enriched uranium	RCS	reactor coolant system
LHD	load-haul-dump	SCRA	storage cask receiving area
LLW	low-level waste	SCSF	surface cask storage facility
LN ₂	liquid nitrogen	SF	spent fuel
LSA	low specific activity	SFPF	spent fuel packaging facility
LWBR	light water breeder reactor	SFRSS	spent fuel receiving and storage station
LWR	light water reactor	SFSF	spent fuel storage facility
M&M	men and materials	SHLW	solidified high-level waste
MFBM	thousand board feet measure	SNM	special nuclear material, i.e., enriched uranium and plutonium
MFRP	General Electric Company's Midwest Fuel Reprocessing Plant	SRP	Savannah River Plant
MOX FFP	mixed oxide fuel fabrication plant	SSC	sealed storage cask
MP	mine production	SSCF	sealed storage cask facility
MSRE	molten salt reactor	TBP	tributyl phosphate
MTHM	metric ton heavy metal	TD	theoretical density
NAA	normal access area	TN	Transnuclear Inc.
NAC	Nuclear Assurance Corporation	TRU	transuranic
NAS	National Academy of Sciences	TSA	transuranic storage area
NASA	National Aeronautics and Space Administration	TWCA	Teledyne Wahchang Albany
NFS	Nuclear Fuel Services	U-F	urea-formaldehyde
NHLSW	non-high-level solid waste	VE	ventilation exhaust
NLI	National Lead Industries	VOG	vessel off-gas
NRC	Nuclear Regulatory Commission	WBS	water basin storage
NSSS	nuclear steam supply system	WBSF	water basin storage facility
NWTS	National Waste Terminal Storage	WBSF-PF	water basin storage facility for packaged fuel
ORIGEN	a computer program to calculate isotopic composition of irradiated nuclear fuel	WCC	waste calcination cell (cubicle)
ORNL	Oak Ridge National Laboratory	WCF	waste calcination facility
ONWI	Office of Nuclear Waste Isolation	WIPP	Waste Isolation Pilot Plant
OWI	Office of Waste Isolation	WTEB	waste tank equipment building
P-T	partitioning and transmutation	WVC	waste vitrification cell
PCWS	plant cooling water system	WVF	waste vitrification facility

MEASUREMENT UNITS AND CONVERSIONS

MEASUREMENT UNITS AND CONVERSIONS

This report preferentially uses the metric system of measurements as defined by the International System of Units (SI). Common English units are often also included in parentheses. Prefixes used with the metric units are defined as follows:

<u>Prefix</u>	<u>Abbreviation</u>	<u>Factor</u>
giga	G	10^9
mega	M	10^6
kilo	k	10^3
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}

The following lists identify the symbols used in this report and the factors for converting between the SI and English units.

Symbols for metric units used in this report are:

<u>Symbol</u>	<u>Name</u>
$^{\circ}\text{C}^{(a)}$	degree Celsius
d(a)	day
g	gram
h (or hr)	hour
ha	hectare
kWh	Kilowatt-hour
J	joule
l	liter
m	meter
min	minute
<u>M</u>	gram-mole/liter
MT	metric ton
MW-hr (or MWh)	megawatt-hour
s (or sec)	second
W	watt

a. Units which are not strictly SI but which are widely used.

Symbols for other units used in this report are:

<u>Symbol</u>	<u>Name</u>
atm	atmospheric pressure
BTU	British thermal unit
Ci	curie
°F	degree Fahrenheit
ft	feet
gal	gallon
in.	inch
lb	pound
MFBM	thousand board feet measure
psi	pounds/square inch
R	roentgen
rem	roentgen equivalent man
yd	yard
yr	year

To convert metric to English, multiply by:

<u>Metric</u>	<u>English</u>	<u>Factor</u>
°C	°F	$(^{\circ}\text{C} \times 9/5) + 32$
cm	inch	0.3937
ha	acre	2.47
kg	lb	2.205
km	mile	0.6214
ℓ	gal	0.2642
m	ft	3.281
m ²	ft ²	10.76
m ³	MFBM	0.424
m ³	ft ³	35.31
m ³	gal	264.2
m ³	yd ³	1.308
MT	ton	0.9070
W	BTU/hr	3.413
W-s/kg-°C	BTU/lb-°F	2.39×10^{-4}
W/m-°C	BTU/hr-ft-°F	0.576

To convert English to metric, multiply by:

<u>English</u>	<u>Metric</u>	<u>Factor</u>
acre	ha	0.405
BTU	W-hr	0.2931
BTU/lb-°F	W-s/kg-°C	4187
BTU/hr-ft-°F	W/m-°C	1.735
°F	°C	$(°F-32) \times 5/9$
ft	m	0.3048
ft ²	m ²	0.0929
ft ³	m ³	0.0283
gal	ℓ	3.785
gal	m ³	3.785×10^{-3}
inches	cm	2.540
lb	kg	0.4536
mile	km	1.609
MFBM	m ³	2.360
ton	MT	1.103
yd ³	m ³	0.7646